guide to CROP PROTECTION in Alberta

PART 2
NON CHEMICAL CONTROL

of Weeds, Insects, Diseases
for maximum economic yield

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GUIDE TO CROP PROTECTION IN ALBERTA

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PART II - NON CHEMICAL

Edited by
Crop Protection Branch
Alberta Agriculture

THIS GUIDE IS THE FIRST EDITION OF A NEW PUBLICATION. WE HAVE ENJOYED PRODUCING THIS PUBLICATION AND HOPE YOU WILL FIND IT USEFUL.

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Non-Chemical Pest Management

Specific uses of all nonchemical techniques are explained in the sections dealing with different pests. This section introduces the range of possible control strategies. In considering any technique the farmer must be aware that the control method for any pest may actually encourage another. Some control techniques also have drawbacks because they predispose the land to soil erosion, moisture loss or lower the yield potential. In other instances the best control method may not enable the producer to make the best of current market opportunities. Generally, if good pest management is practised routinely, a short term change to take advantage of specific opportunities should not prove disastrous, but continued violation of sound pest management principles can lead to pest population build-ups and a major outbreak.

Preventive controls

Many pest problems can be prevented by rather simple and common sense management practices. Some attention to the following practices will save hours of labor and a great deal of money if they prevent a pest problem from becoming established:

- Use weed and disease-free seed. Many plant diseases are seed borne. Do not seed the pest along with your crop. Totally weed-free seed is impractical, but ensure that the weed seed content is minimal and that seeds of species not already present on your farm are not present in the seed you sow.
- Grow resistant varieties whenever possible. In some instances a resistant variety may not have as high a yield potential as a nonresistant variety, but the loss of even one crop to a pest will more than cancel any yield advantage.
- Use fallowing practices that prevent pests from reproducing. Control weeds before they produce seed; destroy disease containing crop residue. Never allow a pest species to become firmly established.
- Encourage the natural enemies of as many pests as possible.
- Scout your fields to identify new pests and to monitor pest populations. If you note the start of a pest build-up, take immediate action to control the pest, salvage the crop by cutting the worst areas for forage or take other measures as required. If an overall pest build-up is noted, consider rotation into a nonsusceptible crop.
- Always practise good sanitation. Clean equipment before moving it to new fields; clean granaries before filling to remove stored grain insects; do not drag weed parts to new areas of the field.

Many preventive practices are a minor nuisance to conduct but they can save major problems later. The above-mentioned recommendations are only a sample. Think of things you can do on your farm, for example, test seed for weed or disease contamination.

GENERAL

Quarantines and inspections

In order to protect our agricultural industry, a number of regulations have been developed which govern the movement of plants and plant products. These regulations are intended to reduce the introduction of plant disease (or pests) and restrict their spread.

A plant disease introduced to a new area is more likely to cause an epidemic resulting in major yield losses because crops grown in that area will not likely have any resistance to this disease.

There are several types of quarantine measures:

Embargoes: The purpose of embargoes is to exclude plant material on which a pest is likely to enter. Embargoes sometimes operate only at certain times of the year. Table stock potatoes intended for domestic use may only be imported during the winter and early spring from certain regions of the United States, where a specific disease organism may be present e.g., Columbia root-knot nematode. This organism is not known to occur in Canada. Therefore seed potatoes for commercial planting may not be imported from this region.

Inspection: At port of entry or at point of origin, plants and plant products are inspected to detect infested or infected material. If the plant cannot be treated in such a way as to kill contaminating pest organisms, the material will either be destroyed or returned to its point of origin. Flower bulbs imported from Europe are subject to inspection. Flower bulbs may carry disease organisms such as potato cyst nematode that could be of consequence to Canadian agriculture when the bulbs are grown on potato land.

Controlled entry: Plants and plant products will be allowed to enter this country provided that disinfection, disinfestation, or fumigation treatments will kill all stages of any pest or disease present in the consignment. Cereal seed of a known variety that has been multiplied (built up) in another country during the fall and winter months must be treated prior to being brought into Canada.

Postentry and intermediate quarantine stations: These stations are used especially for the transfer of vegetatively propagated materials. Only small lots are permitted to enter. They are grown in an approved quarantine area and thoroughly inspected for pests and disease over a period of months or years before they can be offered for sale. This is done routinely with such material as apple, cherry and grape bud wood that could carry diseases not present in Canada.

Public awareness and information dissemination: In many cases the general public is unknowingly responsible for transporting plant diseases, insects, and weeds. It is therefore important to make the travelling public aware of the great dangers from the introduction of new pests into Canada.

For example Canada presently has a number of diseases that are under quarantine measures. These diseases are controlled by restricting imports that could be contaminated and by restricting trade within Canada.

Quarantinable diseases —

Dwarf bunt of wheat: This is a disease of winter wheat found in Ontario and the intermountain valleys of southern British Columbia. It causes yield and quality reductions and loss in export markets because of embargoes placed on contaminated seed.

Flag smut of cereals: This disease is currently not found in Canada. It can persist for many years in the soil. Importation of seed into Canada is restricted by plant quarantine regulations.

Karnal bunt of wheat: This disease does not occur in Canada. Strict regulations exist governing importation of seeds of host plants from areas such as Mexico, where the fungus is present. The disease not only affects yield but is detrimental to the quality of grain for food, feed, seed, or export intentions.

Columbia root knot nematode: This nematode affects potatoes, alfalfa, field peas and root vegetables. It is not found in Canada.

Golden cyst nematode: This nematode affects potatoes, tomatoes and related plants. Found only in eastern Newfoundland and on Vancouver Island B.C. it may persist in a dormant state in the soil for 15 or more years.

Potato wart: This disease is found only in Newfoundland and Labrador. Not only are the potatoes under quarantine restrictions but so are vehicles, machinery, construction equipment, sand, soil, sod, used bags, sacks and covers that could have had contact with contaminated potatoes.

Head smut of corn: This disease occurs in British Columbia, Manitoba southern Ontario and Quebec. In 1985 it was found for the first time in Alberta. Spores can survive in the soil for up to 10 years.

Verticillium wilt: This disease occurs in south-central British Columbia, southern Alberta, Saskatchewan, west-central Ontario and Nova Scotia.

The Plant Quarantine Act prohibits importation as well as propagation, sale or movement of plants which serve as alternate hosts for crop diseases. This includes seeds of all species, hybrids and horticultural varieties of the **Berberis, Mahonia, Mahoberberis** and **Rhamnus** genera which are susceptible to stem rust of wheat and crown rust of oats.

Weed and disease free seed - certified seed —

Use seed which is sound and free from weed seed, sclerotia, ergot bodies, smut or bunt balls, infested or infected debris which could harbor disease spores. Contaminated seed is one of the major means of spreading pests over long distances and introducing new pests onto the land. Seed can be sent for disease testing to Agriculture Canada, Seed Biology Laboratory, Seed-borne Disease Unit. They can test for the following diseases below.

SERVICES AND FEES - 1988 Agriculture Canada, Seed Biology Laboratory, Seed Borne Disease Unit

Crop	Disease	Fee	Sample Size (*# seeds)
Crucifers	Alternaria	29.00	1,000
	Black rot	29.00	30,000
	Black leg	29,00	5,000
Cereals and grasses	Loose smut (wheat barley)	19.00	1,000
	Surface borne smuts and bunt	19.00	1,000
	Leaf stripe - barley	19.00	1,000
	Net blotch - barley	19.00	1,000
	Glume blotch - wheat	19.00	1,000
	Spot blotch - wheat	19.00	1,000
	Fusarium - wheat	19.00	1,000
	Barley stripe mosaic virus	29.00	5,000
Pulse crops	Ascochyta blight	29.00	1,000
Soybeans	Phomopsis (Diaporthe)	29.00	1,000
	Soybean mosaic virus	29.00	5,000
	Stem break	29.00	1,000
	Anthracnose	29.00	1,000
	Pasmo	29.00	1,000
Forage legumes	Verticillium Wilt	29.00	10,000

Other tests available upon request.
*For certified or commercial seed (bean) please submit 2 kg of seed, for foundation seed, submit 4 kg.

Please make cheque payable to: The Receiver General for Canada
Sample should be submitted with payment to: **Seed-Borne Disease Unit Laboratory Services Division, Bldg. #22, Agriculture Canada, Central Experimental Farm, Ottawa, Ontario K1A 0C6**

Sanitation

This control measure includes all activities used to reduce or eliminate the presence of pests in the field and storage facilities as well as prevent the spread to healthy plants and plant products.

Burying of disease-infected crop residue by plowing or deep cultivation prevents fungal spores produced on the surface of crop residue from being released into the air to infect growing plants. Burying fungal resting structures such as ergots and sclerotes more than two inches deep prevents the production of spore-producing mushrooms.

Tillage promotes the decay of crop residue and root systems. This reduces the length of time disease organisms are able to survive on host material.

Disease spores may be present in soil, plant residue, hay, manure or feed materials. Movement of these can result in both long and short distance spread of disease. Alfalfa hay infected with verticillium wilt can be moved province wide through hay sales. Take-all of wheat can be moved into a clean field in soil contaminating the harvesting equipment. Clean cutting and careful harvesting reduce the reinfestation of forage fields, the resulting new growth will be relatively disease free.

The presence of some diseases require a thorough disinfection of all handling equipment and storage facilities. This prevents the contamination of uninfested seed or new seed brought on to the premises.

If Septoria glume blotch or tan spot problems occur in dryland wheat, then the only disease control alternative is turning under the straw or a crop rotation. Turning under the straw in continuous wheat reduces the abundance of the fungus infested surface straw residue. The lowered inoculum level resulting from cultivation could delay the maximum build-up of disease by one to three weeks. If this disease delay occurs in mid to late July at the critical postflowering stage, the yield increase resulting from cultivation could be in the range of 10 to 25 per cent. The use of minimum till would allow the diseased crop residue to remain on the soil surface maximizing the disease potential.

Rusts and smuts of wheat are not affected by zero tillage since rust spores are moved in by wind from the U.S. and smuts are borne in or on the seed.

If minimum tillage coupled with continuous cropping is here to stay, our disease control strategy must change. Resistance to leaf diseases must become a plant breeding priority, but where genetic resistance is nonexistant we might have to resort to fungicidal control, particularly on irrigation land.

Consequences of adoption of minimum tillage.

For Farmers

- loss of a cultural disease control procedure
- an upward shift in the importance of plant diseases
- possible use of foliar fungicides
- soil conservation and reduced tillage costs. - a change in the weed species which are prevalent.

Research and extension

- breeding crops (cereals) resistant to leaf diseases and root rots
- research on fungicide efficacy (application rates, timing and costs)
- development of disease forecast systems.

Minimum or zero tillage helps conserve soil moisture, reduces soil erosion and lowers labor and fuel costs. Unfortunately, it can increase certain weed and disease problems or cause a shift in the pests that are present in the field. Minimum tillage is known to increase the incidences of root rots common root rot, (take all) in cereals.

Crop rotation

Crop rotation is an extremely important tool for reducing farm pest problems. Annual weeds can be controlled through the use of forage crops, while perennial weeds are controlled when annual crops are planted. Insects, and residue-borne fungal and bacterial diseases are controlled by the lag time between susceptible crops. As well as allowing for these benefits, a good crop rotation improves the condition of the soil.

There are two types of rotation. The so-called short rotations may include a cereal crop or two, an oilseed and perhaps summerfallow. The short-term rotation allows the producer to select crops in response to market conditions and to select crops which are resistant to some pests. The short rotation also allows the growing of crops responsive to herbicide applications which control a variety of weeds. Short rotations do little or nothing to enhance the soil unless a green manure crop is included as part of the fallow.

Longer term rotations can include perennial crops, including forage legumes and grasses, which not only break weed and pest cycles but also enhance the soil. Longer term rotations are more difficult to change in response to the market and require careful planning and preferably a mixed farm operation.

Rotations can be used to eliminate or reduce disease levels in the field. Growing crops which cannot be infected will cause the disease organisms to die out. The number of years between successive crops depends on how fast the disease organisms to die out. Crop rotation is particularly effective against short-lived soil and residue borne diseases.

Short lived diseases - The effectiveness of crop rotation as well as the suggested time interval between crops will vary with the disease. Effective control through crop rotation is only possible with diseases that are specific to their hosts (for example, flax and sunflower rusts) or diseases that survive only on living plant tissue or its residue (for example, scald of barley). For these diseases, fairly short rotations are usually effective. However, infectious spores are often produced for years on crop residue and may also blow in from adjacent fields. Crop rotations are not effective unless accompanied by other management practices, such as plowing under or deep tillage of the crop residue, controlling volunteer seedlings and weeds, and not growing susceptible crops adjacent to the previous year's stubble.

Long lived diseases - Crop rotation becomes less effective when disease-causing organisms are not host specific, produce long-lived spores or can survive for many years in the soil. Examples of these include: verticillium wilt of alfalfa, sclerotinia white mold of canola, and root rots of barley, canola and wheat. For these diseases, long crop rotations are useful in reducing, not eliminating, the populations of the disease-causing organisms. Susceptible crops can only be grown once every three, four or five years, in order to reduce disease levels in heavily infested fields. Crops must be watched closely for symptoms of disease. When they are identified, their significance should be evaluated for the following year's cropping sequence. Cropping sequence in which crops are planted in a particular field is an important part of disease management.

Canola in the Peace region should not follow fescue, since the high organic content and moisture holding capacity of the sod increases the amount of root rot in the canola crop. The high organic content of the sod will tie up available soil nitrogen needed by soil microorganisms for the sod breakdown. Fertilizer levels have to be adjusted to compensate for this temporary nitrogen deficiency. Plant diseases are only one important part of this decision.

Factors which must also be taken into consideration in planning crop sequences in a field are:
-weed history
-possible herbicide residues
-soil fertility
-volunteer growth from the previous crop.

Volunteer growth may cause serious competition and/or seed separation problems as well as supporting the growth of plant diseases.

Crop rotation assists in control of insects by continually changing their food supply and living conditions.

A crop rotation which alternates between susceptible and immune crops will discourage the build-up of pest populations. For example, wireworms can be controlled almost completely if cereals are rotated with a nongrass crop. As cereal and broadleaved crops tend to have different

Disease considerations in crop rotations

Crop	Order of Seriousness	Should not be grown after	Reason
Barley, Wheat	1	Barley, Wheat	Leaf diseases, Root rot
	2	Corn	Scab (head blight)
	3	Fall rye	Ergot
Flax	1	Sugar Beets, Peas, Lentils, Summerfallow	Rhizoctonia
	1	Flax	Rhizoctonia (rust where rust susceptible varieties are grown)
Fall Rye	1	Rye	Ergot
	3	Wheat, Barley	Ergot
Canola and Mustard	1	Canola, Mustard Rapeseed	Sclerotinia, Rhizoctonia, Blackleg
	2	Sunflowers, Lentils	Sclerotinia
Sunflowers	1	Sunflowers	Sclerotinia Verticillium, Downy mildew, Rust
	1	Canola, Rapeseed and Mustard	Sclerotinia
	2	Lentils	Sclerotinia
Field peas	1	Field peas, Fababeans	Ascochyta, Bacterial blight
	2	Sugar beets, Alfalfa, Flax, Beans, Lentils,	Rhizoctonia Pythium, Fusarium
	2	Sunflowers, Lentils, Canola, Rapeseed, Beans Fababeans, Mustard	Sclerotinia
Sugar beets	1	Flax, Peas	Rhizoctonia
	3	Potatoes	Rhizoctonia, Fusarium tuber rots

Rating: 1 - Severe - there is a great risk of severe disease development.
2 - Moderate - there is a medium risk of severe disease development.
3 - Light - there is a low risk of severe disease development.

insect pests, rotation will discourage their build-up. Switching to a different cereal crop can eliminate certain host-specific pests. Barley thrips and wheat midge, for instance, infest barley and wheat (respectively) more severely than other cereals.

Crop rotation is sometimes enhanced by growing different crops in mixed populations. Examples are: underseeding cereal with clover, or a grass-legume hay combination, mixed grains, or a silage mix of peas and oats. Insect populations in such plantings are normally more complex and thus more stable, providing a better balance between pests and their natural control agents.

The use of fallow in a rotation is controversial. Summerfallow contributes to soil erosion,and it is recommended only for areas where moisture is very limited even then alternative practices for weed control are encouraged. It is preferable to combat weeds by using crop rotation and crop competition.

Despite some problems fallow plays an important role in breaking up the life cycle of diseases and insects; the benefits in controlling perennial weeds are well known. However fallow has been practised so long in southern Alberta that many of our current pests are those which have adapted to fallow (e.g., annual weeds, cutworms, etc.) Perhaps breaking up the normal fallow-crop rotation would be beneficial.

Crops commonly used in rotations

Spring-seeded annual crops - The first flush of weeds can be destroyed by tillage prior to spring seeding. However, populations of late germinating weeds, such as green foxtail and shepherd's-purse, may increase if a field is repeatedly spring seeded. Spring-seeded annual forages are an alternative to perennial forages, especially on weedy land. Annual forages should be cut before weed flowering, to prevent formation of viable seeds.

Legumes - Leguminous cover crops prevent erosion; fix nitrogen in the soil, decreasing the need for nitrogen fertilizer; loosen the subsoil, improve soil structure and organic matter; smother weeds; and starve insects and diseases of nonleguminous crops.

Underseeding or companion seeding - The principle of underseeding or companion seeding is to crowd weeds out. For example, planting clover beneath cereals provides strong competition for weeds. After cereal harvest, the clover can be used as forage or green manure. Companion seeding means growing several varieties at the same time, such as a grass and a legume mixed grains, or a silage mix of peas and oats. These plantings ensure a variety of habitat for beneficial insects and exploit light and soil nutrients to the detriment of weed growth.

Row crops - Summer annuals, like wild oats, are usually problems where spring grains are grown continuously or in rotation with summerfallow. The problem can be reduced by using row crops. Some common row crops are sugar beets, potatoes, field corn, peas and beans. When planning a rotation with grain crops, select a row crop according to the climatic conditions in your area. As a good rotation for weed control, include both summer row crops and winter or early spring grain crops such as fall rye, winter wheat, or early barley. Row crops that are unrelated to common oilseeds and grains are helpful in preventing the build-up of many common insects and diseases.

Perennial Forage crops - or cultivated pastures are effective in reducing populations of annual weeds and some insects. Annual weeds must be controlled during the seedling stage of the crop. Once perennial forages are established, mowing and competition will suppress weeds. Eventually, vigorous competition will eliminate annual weeds almost completely. The forage stand must be left for a number of years to allow buried weed seeds to rot. Some weed seeds will stay dormant and germinate during the year following breaking. The first year after breaking a forage stand is very critical because the field will be reinfested if prompt control measures are not taken. With careful management practices, none of the weeds grown out the year after breaking should ever produce seed. This land can remain clean for many years. Leaving parts of the forage uncut provides a lasting habitat for beneficial insects and birds. Some perennial grasses especially crested wheatgrass have been shown to compete better than perennial legumes. The competitive ability of crested wheatgrass, compared with several perennial weeds, shown below.

Effect of crested wheatgrass on density of perennial weeds

	Before grass (1) sown	Year after grass was sown (2) 1	2	3	4	5	Percent reduction
Perennial sow thistle	112	61	3	1	0	0	100
Toadflax	187	108	27	2	0	0	100
Canada Thistle	27	27	17	5	2	0	100
Field bindweed	93	70	63	54	53	48	49

(1) Number of weeds per square yard.

(2) Good stands of the grass were obtained on all plots; over 2,000 seedling plants per square yard. Data represent averages of 4 plots. From: Pavlynchenko and Kirk.

In the year of establishment of a perennial crop stand, weed control can be as simple as mowing or cutting before weeds go to seed. Weeds can contribute to the feed value of hay; after they are cut the crop will gain a competitive advantage.

Perennial crops should be left down for three to five years. This allows time for competition against weeds and depletion of buried weed seeds. Weed control is critical immediately following breaking because the dormancy of many seeds will be broken and they will germinate as soon as the soil is plowed.

Fall seeded crops - Fall rye and winter wheat are effective in weed control programs where it is practical to grow them. Fall rye will grow much further north than winter wheat, but even rye can be killed by snow mold fungi in the Peace region when snow cover remains late into April. These crops give early season competition to weed seedlings and their early harvest date enables a partial summerfallow for the balance of the year. This two-pronged approach provides for control of both annual and perennial weeds.

Winter annual weeds are a problem in fall-seeded crops. These weeds emerge with the crop, and form overwintering rosettes. In the spring, the winter annual weeds flower and set seed long before the crop can be harvested. Some winter annuals can be controlled in the crop by using 2,4-D, others must be controlled by rotations.

Greenfeed - Greenfeed crops can be used against very heavy weed infestations where profitable cereal production is questionable. Oats are generally used because they make better hay or silage than other cereals. The greenfeed crop should be cut or thoroughly grazed before the weeds bloom. By cutting at this time, the greenfeed will be free of weed seeds, and a population of weeds will have been harmlessly grown out. If weather conditions are good for regrowth, a second cutting or tillage to prevent weeds from producing seed may be necessary. Since seed production can take place without a great deal of additional top growth, weeds must be watched carefully. Alternatively, the forage can be turned under for both green manure and weed control.

In the wetter parts of the province, a combined greenfeed and summerfallow operation can be effective. Seed greenfeed early in the spring, then after the infested crop has been pastured, hayed or silaged, use tillage operations. The strategy is to begin summerfallowing prior to the seed-set of annuals and when perennials have depleted their root stores of nutrients.

Variety selection - Enhance the benefits of crop rotation by selecting varieties that will discourage local pests. Pick a variety well suited to the growing conditions, and thus vigorous enough to withstand some pest damage, or select a variety that matures earlier (or later, in some cases) than the pest does, and so avoids damage.

Some varieties have been bred to resist insect attack. For instance, solid-stemmed wheat varieties are resistant to wheat stem sawfly and most of the alfalfa grown in the western U.S. is resistant to spotted alfalfa aphid.

PREVENTING WEEDS

Sow weed-free seed

Home-grown seed should be cleaned thoroughly to remove weed and foreign crop seeds. Purchased seed is not usually weed-free, so a certificate from the supplier should be obtained to determine the numbers and kinds of weed seeds present. A certificate of analysis lists the species and the numbers of weed seeds found in a seed sample. Seed dealers must supply a certificate to buyers upon request.

Graded seed will allow varying levels of weed seeds to be present, depending on the crop. An example of the standards is shown below; the higher the grade, the fewer weed seeds allowed.

MAXIMUM NUMBER OF WEED SEEDS FOR 500 GRAMS OF CROP SEED

Canada Seeds Act (Effective July, 1987)

	Total Weed Seeds	Total Other Crops
Canada Registered -1	3	2
Canada Registered -2	6	4
Canada Certified -1	3	4
Canada Certified -2	6	10
Canada -1	10	25
Canada -2	20	50

These standards apply to barley, buckwheat, lentils, lupine, rye, sainfoin, etc. With minor variations they apply to wheat, canola, flax, and oats.

If new weeds are found in a crop, they should be destroyed before they reproduce. New perennial forage stands in particular should be checked for weeds.

Prevent weed seed formation

A weed can produce a few hundred to several hundred thousand seeds depending on the species and the conditions. These seeds add to the soil seedbank causing future problems. Preventing seed production is an important control strategy. Mowing some weeds can be effective. Other weeds with different growth habits are only slightly affected by mowing and simply continue to flower and produce seeds below the height of the mower. Tillage of fallow fields must be conducted prior to seed set. Extremely weedy crops can be cut for feed before the weeds go to seed. If viable seeds exist, the feed should be put up for silage since seed viability is usually destroyed in the ensiling process.

Prevent spread through feed and manure

Weed seeds may remain viable after passing through animals, resulting in contaminated manure. Screenings used for feed should be finely ground, cooked or pelleted to ensure destruction of all the weed seeds. Poultry are most effective in destroying weed seeds as their crops grind the seeds. In order of decreasing effectiveness are sheep, horses, swine, and cattle.

Practice fenceline and headland control

Fencelines and headlands serve as a habitat for beneficial insects and wildlife. Disturbing these sites may not be necessary as long as they do not act as a refuge for weeds or insect pests. If fencelines, headlands and roadsides are sources of infestation, try planting them with native plants and grasses which are adapted to our climate and growing conditions, and thus competitive with weeds. Mowing or grazing uncultivated wastelands helps to control weeds. If possible, delay mowing or intense grazing until late July, to allow ground nesting birds to raise their broods.

Prevent spread with soil and equipment

Weed seeds and vegetative parts move with farm equipment and soil. Long distance transport is responsible for the introduction of new weeds to previously clean areas. Industrial equipment, seed and used farm machinery are the worst offenders. Equipment should be cleaned before moving from one area to another. Grain and soil should be tarped when being transported.

PREVENTING INSECTS

Tillage practices

Tillage provides protection against some insects. Properly timed before seeding, after harvesting or during summerfallow, it will reduce populations of insect pests that spend part of their life cycle in soil or stubble. Tillage is used to starve insects in the spring or during fallow, to prevent egg-laying, and to expose overwintering insects to predators and inclement weather.

Some egg-laying insects are attracted to green plants during the late summer/fall season. This is especially true in fallow fields that are bare except for volunteer or weedy growth. Working down green growth will protect the field from egg deposits of such insects as grasshoppers, army cutworm and red-backed cutworm.

Pale western cutworm can be prevented from laying eggs by letting the soil form a crust from August 1 to September 15. No cultivation, grazing, or soil disturbance of any kind should take place during this time. These cutworms prefer to lay their eggs in soft, dusty soil, and if the soil has even a slight crust, the moths will not lay their eggs.

Soils crusted from late July until late September on summerfallow will prevent egg laying by red-backed cutworm moths. If weed growth develops in August, however,it should be destroyed as red-backed cutworm moths prefer to lay their eggs in weedy summerfallow.

Newly hatched insects may be starved by cultivating or removing new green growth, the food source for grasshopper nymphs, grubs of red turnip beetles and cutworm larvae. Young cutworm larvae may be starved before spring seeding by allowing volunteer growth to reach 3 to 5 cm, cultivating, then seeding 10 to 14 days later. Cutworms can be found by digging 2 to 3 cm below the soil surface in damaged areas. Plants severed at or just below the soil surface indicate a of cutworm infestation.

Maintain the area weed free through the hatch period. It is not unusual to have two or three of the major grasshopper species infesting a quarter of farmland and to have a hatch period last for up to six weeks. Summerfallowed fields should be regularly monitored even though an initial hatch of insects has been successfully controlled.

PREVENTING DISEASE

Use resistant varieties

This is the most efficient and cost effective means of disease control. There is no additional operating cost, no hazard to the farmer or the environment and there is little or no disease carryover in the crop residue. Resistance to specific diseases can be through i) early maturity, escaping the infection period; ii) endurance, vigorous growth permits the plants to mature despite disease attack; iii) resisting infection, plants have some structural or physiological characteristic which prevents infection.

A great deal of money and effort is expended in Canada and on a world wide scale to breed crop plants for disease resistance.

Past successes in breeding for disease resistance have resulted in effective control of bunt, smut and rust in cereals. In the 1930s, it was not unusual to lose up to 30 per cent of a wheat crop to bunt, or perhaps 50 per cent of the crop to stem rust. Plant breeders have been able to incorporate resistance to these plant pathogens into suitable crop varieties.

Resistance to a specific disease in a given crop can last for a few years and sometimes indefinitely, depending on the causal agent. In the case of abiotic (nonliving) causes, such as cold tolerance, a cereal variety selected for its ability to withstand cold temperatures will always have that ability. If the cause of disease is biotic (living), such as stem rust resistance in cereals, this trait may last only for a short time period because of the rust's ability to undergo genetic changes. Plant breeders then have to go back to the drawing board.

An example of disease resistance that lasted for many years was where "jet" genes were incorporated into barley against loose smut. This resistance, present in many barley varieties, held up until recent years. New strains of loose smut fungus on the prairies have now overcome this resistance. Consequently, Leduc and Tupper barley with new genetic resistance, are the only barley varieties that are loose smut resistant.

There are two other categories of disease reactions: (1) intermediate which denotes varieties which may develop disease under conditions which are favorable for disease spread, growth and multiplication. Normally, these varieties do not require protection, and (2) susceptible which denotes varieties that require protection or should be avoided where a specific disease is a problem.

Environmental factors such as rainfall, temperature, fertility, planting dates and soil reaction influence the degree of resistance shown to a crop disease.

Crop competition

Strong, healthy crops have a competitive advantage over weeds but crop species vary in their ability to compete. Perennial crops, after the year of establishment, provide very good competition for weeds. Fall rye and winter wheat compete very well because they resume growth in early spring before weeds have emerged. Cereals are generally the best annual crop competitors. Barley is more competitive than spring wheat. Canola is the most competitive oilseed with flax being the poorest. Crops such as lentils, peas and beans are generally poor competitors, owing to low plant populations and slow initial growth.

SEEDING AND FERTILIZING

Crops have some defense mechanisms to deter pests; many can withstand a certain amount of pest damage when they are well nourished and healthy. Like people, crops are susceptible to disease when they are weak or poorly nourished. Planting crops into well prepared seedbeds in good fertile soil will enable them to resist many pests. Place fertilizer where it benefits the crop more than the weeds. Shallow seeding and packing of plump heavy seeds will establish a vigorous stand. Avoid seeding too early; cold will retard seedling growth and make the crop susceptible to disease. Heavy seeding rates to establish early competition to weeds will also compensate for some plants being lost to pests. A vigorous crop can carry more insect damage without yield reduction, so fertility is doubly important if pest problems are anticipated. Because the seedling is most vulnerable and because many insects emerge from diapause (hibernation) just when seedlings emerge, a variety of special seeding practices have been developed.

Rates

Seeding at rates 25 per cent greater than normal will help crops compete with weeds by providing a lush crop canopy. Heavier seeding of cereals allows a margin for crop damage from post-seeding tillage. Under extremely dry conditions, heavier seeding rates will result in the crop competing with itself for moisture. For this reason, heavy seeding cannot be practised in very dry areas.

Heavy seeding can make up for a certain degree of seedling destruction by insects, especially in wheat when wireworm damage is expected. If the infestation is patchy, doubling the seeding rate in susceptible areas is a possible control option. A thorough field scouting program is required.

Depth

Planting shallow into moisture will encourage rapid crop emergence. This will prevent weeds from emerging before the crop. Weeds which emerge before the crop cause significantly greater yield losses than those that emerge after.

Some recommended seeding depths are as follows:

Crop	Recommended Depth of Seeding cm
Cereal, lentils	4 to 5
Canola, flax	1.3 to 4
Forage grasses, legumes	1.3 to 2
Peas, beans (large seed)	6 to 10

Timing

Crops seeded shallow into warm (5 °C or warmer), moist soils germinate and emerge quickly and evenly. Tillage at or before seeding will destroy weed seedlings and give the crop a head start.

By seeding when the soil is both warm and moist, you give the crop a quick start, so it can establish itself before the pest does. Moisture is especially important. For instance, wireworms can destroy 90 to 95 per cent of a crop sown in dry soil compared with 5 to 10 per cent in moist soil.

Early seeding is sometimes used so that crops will be advanced when grasshoppers, cutworms and wireworms are hatching. Another advantage of early seeding of a fast growing variety is that the crop matures before the development of late season pests such as aphids.

Delayed seeding is used to control weeds which germinate under cool soil conditions. One of these weeds is wild oats. Early spring tillage will encourage weed germination. After weed seedlings emerge the land should be tilled and planted. Late planted crops usually yield less and are vulnerable to frost in the fall. Choosing an early maturing crop or variety will minimize yield losses caused by frost. Delayed seeding is not recommended where moisture is extremely limited.

Delayed seeding may also be used to time seedling emergence to occur after a destructive insect stage has passed. For instance, if a heavy cutworm infestation is expected, seeding can be delayed until the cutworm larvae have stopped feeding. It is possible to reduce sawfly damage by delaying seeding, since the stems of young plants are not developed enough to be attractive to egg-laying female sawflies.

There are certain risks associated with late seeding. If spring weather is cold and wet, the pest will be delayed right along with the crop. Late seeding results in lower yields, as early maturing varieties usually yield less. This loss of yield must be balanced with the expected cost of control and the reliability of predicting insect damage. Disease development is affected by the date of planting, soil temperature at planting and depth of planting. If Tobin rape is planted too early and/or to deep, the incidence and severity of seedling blight is increased markedly. Seed treatments will be little help in reducing seedling disease if the soil is cold (below 5 °C) and dry.

Seedbed preparation

A firm, well-packed seedbed maximizes soil moisture contact with the seed. This promotes uniform seeding and seedling emergence. Prior to seeding, the seedbed should be firm enough so that heels should sink no deeper than the thickness of the sole on a normal work boot. This will also provide better depth control with the seed drill.

Fertility

Nitrogen (N), phosphorus (P) and potassium (K) are considered the major macronutrients essential to crop production. N and P are limiting to crop yields in most regions and a few areas are low in K. Soil tests will identify the levels of all soil nutrients. Sulphur (S) is an essential element. Where sulphur levels are deficient, growing crops requiring high sulphur such as canola without additional S would be a poor management decision, resulting in yield losses. Sulphur deficiency occurs in patches, most often on Grey Wooded soils. Canola growing on S deficient soil is stunted, with yellowish cupped leaves, red discolorations and poorly filled or empty seed pods. Soil tests will identify sulphur levels and any deficiency can be corrected by applying S containing fertilizers.

Copper (Cu) deficiency has been identified on sandy and high organic type soils. It contributes to a condition known as melanosis in wheat, where the grains fail to form. The wheat variety Park appears to be very susceptible to this condition. On high organic soils in west central Alberta, Cu deficiency is associated with low yields of barley. Research is underway to find economical ways of adding available Cu to soils to correct these conditions. Other micronutrients that have sometimes been identified as deficient are manganese (gray speck disease of oats), boron (in canola and alfalfa), zinc (in beans), molybdenum (in alfalfa), iron (on alkali soils) and magnesium. If any nutrient is limiting, this becomes the weak link in the production chain and limits yield even though other nutrients may be present in ample quantities.

Vigor of crop plants increases with the use of fertilizers. Phosphorus promotes root development and allows crops to compete more effectively with most weeds. Some weeds, such as green foxtail, respond to nitrogen fertilizer applications thus reducing the crops' competitive advantage. Generally, under wet and cool conditions the use of fertilizer is an effective tool in promoting crop growth. Broadcasting nitrogen stimulates weed growth because the fertilizer is readily available to the weeds, as well as the crop. Banding fertilizer is more advantageous to the crop.

Improper fertilization practices may cause crop problems. Placing too much phosphorus or nitrogen fertilizer with the seed will damage tender seedlings by a simple salt (burning) effect. This reduces the plant stand and yield. Crops under stress from too little or too much fertilizer become more susceptible to diseases. Good plant nutrition is one of the best ways to avoid disease problems. Choice of fertilizer must also be considered. For example, the number of sugar beet plants affected by seedling blight **(Rhizoctonia solani)** can double when ammonium-type nitrogen is used as opposed to nitrate-type nitrogen.

High nutrient levels in the soil can lead to crop lodging since most crop varieties were developed to cope with lower levels of fertilizer inputs. New on the scene are growth regulators. These are chemicals that can dwarf naturally tall-growing crops, reducing their tendency to lodge.

Liming

Certain diseases tend to be associated with alkaline and acid soils. For example, alkaline soils favor take-all of wheat while acidic soils favor clubroot of crucifers.

Alfalfa does best in well drained soils with a pH range from 6.5 to 8 (neutral to alkali soils). At pHs of 6 and lower, the reduced vigor, poor nitrogen fixation, winter survival and susceptibility of alfalfa to disease make it uneconomical to raise this crop. In low pH soils, pH 5 to 6, it makes much more sense to grow alsike or red clover both of which, like alfalfa, add nitrogen to the soil through fixation in root nodules. In northern Alberta, alfalfa is grown on soils around pH 6, but great care is taken with inoculation of the nitrogen-fixing **Rhizobium meliloti** bacteria which do not normally thrive well in soils of this pH. In neutral soils, the alfalfa nitrogen-fixing bacteria do well and can persist for many years in the absence of alfalfa plants.

If land is on the acidic side (below pH 6), is it economical to lime soil? There is no shortage of limestone in Alberta since the entire eastern slope of the Rockies is made from this material. Crushing and transporting the rock are major costs, so liming becomes an expensive proposition. Most field crops, including cereals and oilseeds, will do well at pH 5.5 or higher but anything less will cause significant yield reductions as a result of acid soil conditions. To move a soil pH from 5 to 6 would require about 2 tons of limestone (or marl) per acre at a cost of $25 to $30 per ton. The effect of liming, depending on the nature of the soil, could last three to five years. Would an input cost of $50 to $60 per acre be justified in increased crop yields?

Growers content with an average of 50 bushels per acre of barley on acidic soil with a pH of around 5 would not lime. However, to expect a yield of 100 bushels per acre with intensive crop management on acidic land, liming would be a prime consideration.

Crop placement

Susceptible crops should be planted far away from infested stubble. Surround susceptible crops with diverse plants. Isolating them with summerfallowing strips may help, but the fact that many pests can fly makes isolation of a crop ineffective. For example, bertha armyworm and cabbage root flies can readily find a canola crop.

Crop selection

The crop chosen depends on the weeds and other pests present. The weed species in a field will be dependent on past cropping systems. Choose a crop based on the worst weed problem or the one suspected to be causing the most crop yield loss. For example, in a field infested with both Canada thistle and common groundsel, select a crop that permits Canada thistle control since it is by far the worst of the two. For more details refer to the section on crop rotations.

Physical control

Physical control refers to mechanical or hand controls where the pest is actually attacked and destroyed. Physical controls are used mostly in weed control. Tillage, burning, hand pulling, grazing and mowing are all used to destroy weeds and prevent them from reproducing. Some insects may also be destroyed by tillage, by exposing them to freezing or by killing them during the harvest.

As stated previously, weeds are not controlled through a single cultural operation. Practices such as seedbed preparation, post-seeding tillage, post-harvest tillage and summerfallowing, in combination, are effective against seedlings and perennial shoots. The choice will vary with the region, crop, degree of infestation, soil condition, and the availability of equipment. Soil factors influence the selection of machinery. For example, stones may prevent mowing. Moisture conservation may prevent the use of repeated tillage. All factors must be considered before an integrated control program is developed.

HARVESTING PRACTICES

Strip harvesting

This method applies largely to perennial crops, but may be of some use in annual crops as well. Strip harvesting is useful for two reasons: it preserves natural enemies and prevents mass migration of pests. Whole field harvesting of an infested crop may cause insects such as beet webworm, pea aphid, several of the cutworms, and grasshoppers to migrate to another field and do more damage. If the crop harbors beneficial insects (as it almost certainly will if it is infested), harvesting often destroys them, their habitat and their insect food source. The next parasite generation may even be removed from the field with the harvested crop. Thus the pest often moves to a new crop free of its natural enemies.

An example of the usefulness of strip harvesting can be found in alfalfa pest management. Alfalfa provides an ideal habitat for a variety of insects, ranging from pests (alfalfa weevil, lygus bugs, pea aphid and alfalfa plant bug) to beneficials (damsel bugs, lacewings, ladybird beetles, pirate bugs, wasps, spiders and leafcutter bees). Harvesting alfalfa causes winged pea aphids to migrate and settle on other crops, while many of the beneficials are destroyed. There are for instance, tiny wasps that sting aphids and deposit their eggs in them. These egg-containing aphids will be destroyed with the harvested crop, while winged healthy aphids will migrate to new areas, free of an entire generation of wasps.

To strip harvest alfalfa, one can cut alternate rows, then when the cut rows have undergone some regrowth, cut the original rows, and so on. Or simply leave some strips or patches unharvested.

Early swathing

Early swathing can sometimes save a harvest. By the time sawfly infested wheat reaches maturity, its stems may have collapsed, making it impossible to harvest. Badly infested fields may be saved from pests such as wheat stem sawfly (or weeds) by harvesting early or harvesting as hay or silage.

The time of harvest may affect disease development and yield. Alternaria black spot of canola and mustard attacks pods late in the season. Early swathing of badly infected crops may reduce losses caused by shattering.

Lay swaths so that air can circulate beneath the grain to encourage drying. If canola remains moist, sclerotinia white mold can continue to spread in the swath.

The grains of cereal crops that have overwintered in the swath, particularly under a snow cover, may become infected with fungi, which under certain conditions produce mycotoxins. Mycotoxins are naturally occurring poisonous chemicals that are by-products of a range of fungal species such as **Cephaolosporium, Fusarium** and **Aspergillus. Fusarium** can produce vomitoxin which may be present in hay and grain and result in production losses in animals and illness in humans.

A group of mycotoxins suspected as being carcinogenic and found in Canada are the ochratoxins that have been found in trace amounts in grains that have undergone heating during storage on prairie farms. These mycotoxins are sometimes present in the meat of poultry and hogs that have consumed contaminated feed.

Mowing

Repeated mowing will control perennial weeds by depleting root reserves. Mowing will also prevent seed production of annual and biennial weeds. One-time mowing at flowering will limit or prevent seed development. Root reserves in perennial weeds are lowest when plants are in bud. If only one mowing is planned it should be at this stage. Of course mowing prostrate-growing weeds, such as field bindweed, is not effective.

Mowing is often harmful to beneficial enemies of farm insect pests. Again, farmers need to know the life cycle and habitat needs of the beneficial species, so they can adjust mowing practices. One obvious example is the provision of habitat for birds. Birds consume huge quantities of insects and many of them nest in grass. Early mowing is a prime cause of nestling mortality. Wherever possible, the farmer should avoid mowing (or heavy grazing) until mid to late July.

The key to helping beneficial enemies of insect pests is knowledge. The farmer needs to know the life cycle and habitat requirements of the pest and the beneficial in order to practice better pest management.

HANDPULLING

Small patches of perennial weeds can be pulled up repeatedly to starve the roots. If not eradicated when patches are small, hand pulling becomes ineffective. Pull up plants every two to three weeks until no regrowth appears. Pulling of annual weeds prevents seed set. If weeds are flowering, bag and burn them to prevent seed spread. Hand pulling is feasible in preventing the establishment of new species. Hand rogueing is a routine practice on pedigreed seed farms and is practical even on large areas if the infestation is light.

TILLAGE

One of the earliest methods of weed control used by man was tillage. Tillage is fundamental to integrated weed control. Generally, annual weeds, biennial weeds without extensive tap roots, and perennial seedlings are readily destroyed by tillage. The younger the weed, the easier it is to control. Tillage effectiveness relates directly to the amount of soil disturbance. The greater the disturbance, the greater the effect of tillage on weed control.

Choice of implement depends on residue cover, soil type, soil moisture, growing conditions and weed growth. Blade implements, such as the Noble or Victory blade cultivators, conserve trash but are not very effective under cool wet conditions. Implements which bury plant residues are effective in wet conditions but increase erosion potential. Field cultivators and rod weeders are a good compromise.

Straw Reduction by Selected Tillage Operations

Soil Moisture Conditions	Implement	Surface Residue Reduction (per cent)
Moist	plow	100%
	tandem-disc	50-60
	rod weeder	5-10
	field cultivator	20-30
	chisel plow	15-20**
Dry	blade cultivator	5-10**

** less residue loss with low crown sweeps

Data obtained from Agdex 740-2.

Summerfallow

Summerfallow is used to conserve moisture and nutrients by controlling weeds, while retaining crop residue to protect against soil erosion. Summerfallow is most effective against perennial weeds (because it does not destroy dormant seeds) but is also useful in depleting a portion of the seed bank of annual weeds.

As flushes of weeds occur they are controlled by tillage or with herbicides. Herbicides should be used where tillage is not effective or where soils are extremely susceptible to erosion. Field cultivators with wide sweeps sever roots of both annual and perennial weeds. After the soil has been loosened, a rodweeder will penetrate and provide good annual weed control with a minimum of moisture loss. Blade cultivators can be used in dry areas where minimal soil disturbance is required. As weeds can re-root in moist conditions, tillage should be carried out in hot and dry weather.

One year of summerfallow will help to reduce, but not eliminate, weed problems. Dormant weed seeds will remain to germinate and emerge in subsequent years.

Pre seeding tillage

Shallow tillage (less that 7.5 cm) in early spring encourages most weed seeds to germinate. A second shallow tillage will destroy the emerged seedlings and prepare a seedbed. If crop residue is heavy, a disc type implement should be used. A rod weeder or cultivator will work when less trash is present.

Post seeding tillage

This practice will control weeds that emerge with, or shortly after, cereal crops, sunflowers and potatoes. In some instances post seeding tillage can cause severe crop injury and should be done with caution. Examples of post seeding tillage include inter row cultivation of corn and vegetable crops, and rod weeding of cereal crops when the weeds emerge early and the crop sprouts are below the depth of the rod weeder. Well-established cereals, sunflowers and potato will survive harrowing that will kill delicate, shallow rooted weed seedlings. Crop damage will vary with soil type, weather at the time of tillage, the kind of crop and the depth of seeding. It will be most successful on moderately deep, firm soil. Some crop loss is inevitable and normally acceptable.

Cereal crops seeded 8 to 10 cm deep, and at rates 25 per cent greater than normal can be harrowed or rod weeded **prior to crop emergence** for the control of recently emerged weed seedlings. This operation is risky, and should be done only as a measure of last resort. The concerns are crop injury and increased disease from deep seeding. Cereal seed should be treated with a fungicide to minimize seedling diseases. Tillage prior to crop emergence should be less than 5 cm deep and must be done before crop sprouts are 2 cm in length. This will usually be within 3 or 4 days of seeding. The best weed control occurs when the soil surface is dry.

Post emergence tillage

Wheat and barley seeded 8 to 10 cm deep and up to 25 per cent heavier than normal can be harrowed after emergence. The crop should be in the 1 to 4 leaf stage prior to tillering. Light harrows can be pulled slowly in the same direction as seeding. Post emergent harrowing may delay crop maturity by a minimum 2 to 3 days. Crop plants should be checked during harrowing. Irreparable damage will occur if crop roots are loosened, lost, or damaged. Harrowing should be avoided if the crop is under stress. In a dry spring, this operation will cause more damage than the potential damage caused by the weeds. Generally, barley is more susceptible to damage than wheat. Post-emergent harrowing in fields with heavy trash cover is not recommended because straw will clog the harrows and damage the crops excessively. Herbicides may be a better alternative in many instances.

Inter-row tillage

Tillage can reduce weed populations in row crops such as potatoes and sugar beets but injury to crop roots from inter-row tillage will cause yield reductions. The first tillage should be early and shallow. Subsequent passes can be made if required and if the crop is not too advanced.

Fall tillage

Seedlings of winter annuals and some perennial weeds can be controlled with early fall tillage. Blade cultivators can be used in the Brown soil zones so that stubble remains standing. Field cultivators can be used in the other soil zones. If stubble is sparse, avoid fall tillage and instead till early the following spring. Timing of fall tillage varies with the weed species being controlled. In general, fall tillage is done between crop harvest and soil freeze-up. Both fall tillage and fall spraying are very effective on winter annuals and should be part of most weed control programs.

GRAZING

Grazing serves a similar purpose as mowing in weed control, but grazing is selective unless the animals are very hungry. For this reason grazing may not be as effective as mowing against weeds which are unpalatable because of taste or spines. Grazing is most effective if begun early before the weeds become mature and unpalatable. Repeated removal of weed shoots prevents seed production and weakens underground parts. Rotational grazing encourages growth of desirable forages. Overgrazing will allow weeds to displace desirable forage species.

Sheep are the most effective grazers because they graze close to the ground and because they browse weed species more readily than cattle. Sheep will feed on Canada thistle and leafy spurge. If grazing continues over a period of years, leafy spurge can be effectively controlled. Sheep will select flowers first and then mature leaves. This aids in control because the weed seeds do not mature. Cattle and other livestock will not graze on leafy spurge.

TRAP STRIPS

Crops especially attractive to insects may be grown in strips around fields so that pest insects can be concentrated and killed with insecticides or cultural practices. These attractive crops may simply be the same crop seeded at a different time or may even be a volunteer crop or weeds. For example, corn borer adults lay eggs in the tallest plants. Trap strips seeded earlier or to a faster maturing variety, or planted next to a grassy strip, tramline or headland, have been effective in concentrating corn borers for efficient control.

Trap strips are also effective against sawfly. Sawflies will fly only as far as necessary to deposit their eggs. If trap strips of a resistant (solid-stemmed) variety are planted around the perimeter of a field to be protected, sawflies will deposit their eggs in this strip. Because of the solid stem, larvae do not survive. Sawfly trap strips should be sown earlier than the main crop so that its stems will be more mature and thus more attractive to egg-laying females.

A permanent trap for sawflies is brome grass. Sawflies readily lay their eggs in brome grass which also harbors their parasites.

BURNING

Burning is not recommended. It is often ineffective because the temperature of the fire at ground level is seldom high enough to affect pests in the soil. Fire destroys crop residue and organic matter that could be incorporated into the soil. Burning may be especially destructive of beneficial insects. Fire might not kill healthy larva and pupa of the pest which overwinter beneath the soil but may kill beneficial insects overwintering near the soil surface.

Biological control

The population of all living organisms is limited by the environment. The basic needs of living things food, shelter, an appropriate climate and a reproductive and escape habitat, set outside limits to population density. Pest populations are usually kept far below their maximum numbers by other organisms - predators, parasites, competitors, and disease.

Because of natural and biological control, most of the living organisms in the world do not overwhelm the environment around them. In effect, the farmer has to control only the "leftovers", those pests which survive natural and biological control.

Unfortunately, monocultures are detrimental to natural and biological control. Large fields planted to a single crop, along with the clearance of brush and trees and the drainage of sloughs and wetlands leaves little habitat for the diverse species which keep each other in balance. For example,many of the worst insect pest outbreaks in Alberta are in the south. The soils are low in organic matter and moisture and support a simple biological community. Cultivation and irrigation in this area have disrupted the original biological complex. Land is farmed from road to road and choice of crop rotation is limited. The resulting simple, unstable, monocrop system is vulnerable to colonization by introduced pests. Control measures are limited by the fragile environment which is susceptible to erosion, salinization, drought and decline in soil organic matter. In the north where sloughs and potholes, trees and waste land add diversity to the environment, the outbreaks of serious insect pests are less common.

Farming disturbs the natural balance by frequent tillage and fallow operations which destroy pest and beneficial species indiscriminately. The pest species recovers first, to reach problematic levels before its predators and parasites can build up again. (Predators and parasites need the pest as a food supply).

Over the centuries new insect, weed and disease species have been introduced from other continents, through agricultural seed and produce. These imported insects, weeds and diseases are often free of their natural and biological controls.

More recently, biological controls have been deliberately introduced by bringing the original enemy of the pest from its country of origin. After careful screening, these agents (host-specific insects of disease) are released to go wild. This is called classical biological control. Sometimes the biological agents (or beneficial organisms) are already present but their numbers are insufficient to provide much control. Sometimes the biological agents can't survive the winter. These beneficial organisms may be reared and applied as spray (bacterial or fungal infections) or mass released (insects). Or the farmer can spray specialized foodstuffs on the crop which will help increase the number of beneficial insects. This is called augmented biological control.

As a result of research information about these natural enemies of farm pests, and the pest themselves, the farmer can recognize and use biological control. By developing knowledge about farm pests and beneficial organisms, it is possible to use cultural, physical, and preventive farming methods.

Natural enemies of farm pests are an important control mechanism, particularly for insects. Weeds may also be controlled by disease or insects, and a good deal of effort is being spent on research into biological controls at the present time. Control agents for specific weeds and insects may be found in the appropriate section.

Normally, several steps are involved in undertaking a biological control project:

- The problem must be assessed for amenability to biological control. The characteristics of the problem are examined and the likelihood and effort needed to achieve success determined.
- Literature and background studies on the pest and its enemies are made and the most promising foreign areas selected for search and study.
- Collecting, studying and introducing the natural enemies into quarantine in Canada.
- Clearance tests, releasing and establishing the control agent, and conducting follow-up studies.

Even though an exotic natural enemy may become established in a new area, pest control may still be less than satisfactory for various reasons. In some instances control may be improved through additional or periodic releases of the natural enemies, by using food supplements to encourage immigration and build-up of natural enemies in specific problem areas, by altering cultural practices that may otherwise act to the detriment of natural enemies, and by the judicious use of selective pesticides to minimize harm to the parasites.

Not all pests are equally suited to control by introduced natural enemies; each problem must be assessed individually. Native insect and weed pests often have natural enemies which are made ineffective by farming practices. Whether these pest problems can be solved by introducing additional natural enemies is often unclear, or unlikely. On the other hand, introduced pests are more likely to be controlled by introducing their parasites and predators.

Biological control has been successful against some insect pests of perennial plants, especially those pests that feed externally on the plant and are less mobile. Likewise, there have been more successful attempts to control perennial weeds in range and pasture areas than weeds in crops.

Host-specific insects have been quite useful in controlling weedy plants in many areas. However, the more similar the weed is to an economically important crop, the more difficult it is to find insects that will limit their attack to the weed and not harm the plants of value. For example, artichokes are closely related to thistles, and are susceptible to attack by several insects which could otherwise be used in biological control of thistles. Conflicting opinion as to whether a plant is really a weed may also influence its amenability to biological control. For example, yellow starthistle is valued by beekeepers in California, but it reduces productivity of pastures and grain fields. The losses and benefits of each weed are carefully considered and conflicting interests resolved before biological control is initiated.

Natural enemies, whether introduced or native, require proper management in order to be effective. Various management methods have been developed for natural enemies. Some of these are discussed in the next section.

A search of the area the pest originated from makes it possible to find natural enemies that can be adapted to the pests new habitat. Here again, success is directly proportional to the time and effort expended. By limiting foreign exploration, key parasite species may be overlooked owing to seasonal scarcity or absence caused by pesticide use. Foreign cooperation is especially valuable in locating the desired host plants and pest infestations.

The live beneficial organisms are packaged and shipped to this country as soon as possible after collection. Federal permits are required to import beneficial species and their associated hosts, and the package must be opened in federal quarantine facilities. The parasites are cultured in quarantine and when a reproducing colony is established, and determined to be free of any potentially harmful organisms (diseases, pest species, hyperparasites), permission for its release is granted by federal authorities. The beneficial species may be released in the field directly from quarantine or bred in the insectary to increase its numbers before field releases are made.

Insects intended for biological control of weeds cannot be imported without data on their host range. Therefore, prior to shipment to Canada extensive feeding tests are conducted overseas to assure that plants of value will not be attacked. Additional feeding studies may be required in quarantine prior to release.

COLONIZATION AND ESTABLISHMENT

In attempting to establish the introduced species releases are made at various times in a variety of sites and at different times of the year when suitable stages of the host species are available.

Establishment in the new environment may occur quickly with some species, only after considerable time and massive releases with others, and not at all with still other species. If the introduced species shows promise, it may be desirable to hasten its spread to other areas. A few bio-control agents have already been released in Alberta, others are under test. It is anticipated that several more species will be ready for release in the next few years. Once bio-agents are established farmers and extension agents may collect and spread them wherever appropriate.

BIOLOGICAL CONTROL OF WEEDS

Biological weed control involves the use of living organisms, like insects, fungi and bacteria to control weeds. Agents are useful against single weed species, and are safe for crops and other nontarget plants. This type of weed control has been effective and economical, however, not enough research on biological control of weeds has been done in Western Canada. Work is currently under way on detecting and testing biological control agents for several prairie weeds.

Since most of the major agricultural weeds in western Canada were introduced from Europe, biological control agents are sought there. Potential agents are selected and tested to ensure that they are specific to the target weed. If approved by Agriculture Canada, the agent can be imported and released. If it is successfully established at the first release sites, and causes enough damage to the target weed, it can then be redistributed to other sites. Some insects and diseases spread rapidly enough that redistribution is not needed.

When this type of control is successful, a permanent reduction of the weed population results. The population of the insect or disease persists and continues its attack on the weed without the need for continual re-application. The economic benefits are obvious.

Because of the need for extensive overseas testing and federal government approval, it is not feasible for an individual farmer to become involved in finding and importing new biological control agents. However, once the agents are established in western Canada and available in sufficient numbers, they may be available to farmers for redistribution and release.

Another approach to biological control relies on artificially manipulating populations of the control agent to higher levels of attack than would occur naturally. For instance, a plant pathogen may be made into a spray and applied to a weed in the same way as a chemical herbicide, causing very high levels of disease in the weed. No biological herbicides have been registered in Canada yet, but two are on the market in the United States and research is under way on others both there and in Canada.

Promising biological control agents for Canada thistle, perennial sow-thistle and toadflax are included in this publication.

BIOLOGICAL CONTROL OF INSECTS

Biological control employs natural enemies to reduce pest populations. Enemies of insect pests include pathogens (disease causing organisms) insect predators and parasites, and insect eating vertebrates.

Predatory insects, such as lady beetles, eat many pest insects. They are one example of insects that are predacious in both larval and adult stages. Blister beetles are predacious only as larvae; the adults are foliage feeders and can cause damage to legumes. Their importance as control agents must be carefully assessed before adopting control measures against them.

Insect parasites, such as ichneumon wasps and tachinid flies, eat only one host individual. These insects lay their eggs on, in or near the pest. The larvae usually develop inside the host and kill it when their own larval development is complete.

Pathogens include viruses, fungi, bacteria and protozoa. Some pathogens are being developed commercially to replace or supplement chemical pesticides.

Knowledge of natural enemies is a primary tool in managing insect populations. The farmer needs to know the beneficials so that he does not inadvertantly destroy them and so that he can include them in his pest control decisions. For instance, bee flies are often numerous during grasshopper infestations; their larvae eat grasshopper eggs. Many farmers don't recognize them and try to control them. If beneficials are abundant in an infested field, the infestation may soon be under control. In order to get the greatest benefit from them, farmers should choose control methods least harmful to the beneficial insects.

Insect predators

Lady beetles - The familiar lady beetles (ladybugs or ladybirds) and their larvae are important predators of aphids. They will also eat other plant-sucking insect pests such as mealybugs, scale insects and spider mites. The adults (4-8 mm) are recognized by their nearly round shape and bright colors. Often yellow, red or orange, the beetles usually have a distinctive pattern of black dots on their wing covers. The larvae are about one centimetre long and look like tiny fat alligators. They are often black or bluish in color and spotted or banded with bright colors. When the larva is full grown, it attaches itself by its "tail" to a leaf, stem or other surface. The larval skin splits down the back to reveal the pupa which remains attached to that spot for a few days while the adult is developing within.

The convergent lady beetle, **Hippodamia convergens**, is a very common and widespread species. It is red with black spots and its name refers to the convergent light markings on the thorax. Some species of lady beetles are known to migrate to the foothills and mountains during the fall. There they assemble in great numbers in sheltered locations to spend the winter. Other species overwinter near forage fields and other places where hosts were abundant. In spring, adults disperse before laying eggs. Each larva eats about 25 aphids per day, the adults average 56 aphids per day.

Lacewings - The lacewing adult is a delicate looking insect, bright green except for its golden or copper colored eyes. Its four net-veined wings are all similar in shape and size, and are folded tent-like over the back when not in use. Lacewings may give off an unpleasant odor when handled. Both the adults (about 15 mm in length) and larvae (sometimes called aphidlions) are voracious aphid predators. Eggs are laid on foliage, generally in the vicinity of an aphid colony. Each egg is suspended on top of a thin stalk. Larvae are spiny and alligator-like with long, sickle shaped jaws to grasp prey and suck their body fluids. Larvae of some species carry shrivelled bodies of prey and bits of trash stuck to spines on their backs. Pupation occurs in small, pea shaped silken cocoons. Green lacewings are easily cultured and have been sold as biological control agents for a number of years, chiefly from insectaries in California.

Big-eyed bugs - Nymphs and adults of big-eyed bugs are easily identified: their eyes bulge out beyond the edge of the thorax and the antennae tips are slightly enlarged. Big-eyed bugs are about 3-5 mm in length and grey or buff in color.

Big-eyed bugs are general predators. They feed on many small insects but will concentrate their attack on numerous species, often aphids or mites. Insect eggs and smaller nymphs are preferred prey. When prey is scarce, big-eyed bugs will feed on nectar from the host plant and to some extent on plant tissues in order to survive until prey become more numerous. Eggs of big-eyed bugs are laid near the prey colony. Development from egg to adult takes two to three weeks in summer. A complete generation takes from 17 days to a month or more.

Blister beetles - Blister beetle adults are variously colored: from an iridescent magenta to completely black. They have soft, flexible wing covers and can be distinguished by their shape: the thorax is narrower than either the head or wing covers and, in general, the body is long and narrow. Blister beetles are so called because the bodies of some common species contain cantharadin, a substance which causes blisters when applied to the skin. Spanish fly is a common European blister beetle whose bodies are powdered to make a preparation used medicinally as a skin irritant, diuretic, and aphrodisiac. Blister beetles are abundant during and following years when grasshoppers are abundant because the larvae of many blister beetle species eat grasshopper eggs. Female beetles construct burrows a couple of centimetres under the soil surface. Masses of eggs are laid in a chamber and the entrance to the chamber is closed with soil. The first instar larvae are slender, long-legged and seek out grasshopper egg pods in the soil. As they mature, larvae become grub shaped and less mobile. Adults are foliage feeders that have caused occasional harm to a variety of crops in Alberta including potatoes, sugar beets, cabbage, canola, fababeans and turnips. Damage to plants is made worse by their gregarious nature. Adults swarm and feed in concentrated small areas, sometimes along field margins or near grasshopper egg beds. Usually, the swarms move daily and control is not recommended.

Spiders - Most spiders prefer moist, shaded locations. Low-growing dense flowers attract spiders.

Syrphid and robber flies - Syrphids are black and yellow wasp-like flies that hover near plants; they feed on pollen and nectar, and pollinate flowers. Syrphid larvae eat aphids, leafhoppers and mealybugs. Robber fly larvae eat grubs and grasshopper eggs; adults are general predators.

Ambush bugs, assassin bugs and damsel bugs - These attack a variety of insects, including caterpillars, beetles, leafhoppers and aphids.

Predatory beetles - (adults and/or larvae), including fireflies, and blister, checkered, lady, rove, soldier and tiger beetles - Lady beetles feed on aphids mainly but may also eat potato beetle larvae, thrips and weevil larvae. The others feed on such things as cutworms, cankerworms, grasshopper eggs, mites and cabbage maggots.

Insect parasites

Parasitic wasps - The ichneumon and braconid wasps are two closely related families of parasitic wasps. All ichneumons (over 3,100 North American species - one of the largest families in the insect world) and braconids (over 1,700 North American species) have parasitic larval stages and free living adults. Ichneumon wasps range in size from 4 to 38 mm while braconids tend to be smaller (2 to 15 mm). The adults are colored black and brown but many species have red or yellow patterns. The ovipositor of ichneumon females is threadlike and, for those species which lay their eggs in the tunnels of wood boring grubs, may be several times the body length. Other than a color spot on the leading edge of each front wing, the wings are clear and prominently veined.

Many of our common insect pests have ichneumon or braconid wasp parasites. The bertha armyworm parasite, **Banchus flavescens,** an ichneumon, attacks early stage bertha larvae, grabbing them with her legs and inserting her ovipositor through the caterpillar's skin to lay an egg. The wasp larva develops slowly at first, to allow the host to grow to maturity. Once the parasitized bertha tunnels into the soil to pupate, the parasite rapidly completes its

development, kills the host and chews an exit hole through the cadaver. The mature parasite larva then spins a cocoon within the earthen cell provided by the bertha. The parasite larva overwinters and pupates in the spring. This parasite is a major controlling factor in bertha armyworm populations, particularly at low host densities.

Parasitic flies - Tachinid flies are a very common group (over 1,300 North American species) and are easily recognized. Many of the tachinids are large (5-15 mm in length), dark colored, exceedingly bristly and may appear bee-like. The larvae of all species are parasites of the larvae of butterflies and moths, beetles, sawflies and other insects. Most tachinids lay their eggs directly on the body of the host. The tachinid larva hatches, burrows into the host and feeds internally. When fully developed it leaves the host and pupates nearby. Other tachinids lay their eggs on foliage where they are eaten by leaf eating hosts. The eggs hatch in the host's gut and the parasite larvae burrow into the body through the gut wall.

There are native species of tachinids which attack such important pests as the cutworms, armyworms and tent caterpillars. A tachinid native to the orient and Europe was imported into Canada in 1923 for European corn borer control.

Flesh flies are similar in appearance to tachinids but have grey and black stripes along the thorax. The larvae of these flies have more varied habits than the tachinids. Many are scavengers feeding on dead animal matter; some are parasites of insects. Grasshoppers are parasitized by certain flesh fly species whose females can attack hopping or flying grasshoppers and lay a newly hatched larva on the grasshopper. The larva burrows into the hopper and feeds internally. When the fly larva is mature, it pushes its way out of the hopper's body through the neck, thereby decapitating its host.

Pathogens

Insects are infected by many disease causing organisms (pathogens) including viruses, fungi, bacteria and protozoa. Some pathogens are quite common and frequently cause widespread infection in insect populations. Other pathogens are rare. The effect on the host insect may be severe and their populations can be decimated. On the other hand, some pathogens may produce only mild, long-term effects. Pathogens vary in their specificity to the host. Some viruses will infect only one species or several closely related species. The bacterium, **Bacillus thuringiensis,** on the other hand, infects the larvae of numerous species of butterflies and moths.

Bacillus thuringiensis (or **B.t.**), has been produced in commercial formulations since 1958. Sold under the names Dipel, Novabac, Thuricide and Biotrol, it provides control of many butterfly and moth larvae such as cabbage looper, imported cabbageworm, alfalfa looper and diamondback moth. When **B.t.** is applied with insecticides, lower rates of insecticides can be used and more insect enemies of the host remain to provide continuing control.

B.t. is now registered for use on ornamental and shade trees for spruce budworm, gypsy moth, cankerworm, fall webworm and tent caterpillar. In agriculture, **B.t.** is mainly used on cabbage family vegetables - cabbage, broccoli, brussels sprouts, cauliflower, kale and turnip greens - against imported cabbageworm, cabbage looper and diamondback moth larvae.

B.t. attacks the larval gut and must be eaten by the insect to be effective. Within a few hours of eating **B.t.,** larvae stop eating and death usually occurs within 12 to 72 hours. **B.t.** is applied at the first sign of infestation and at weekly intervals thereafter if necessary.

Nuclear polyhedrosis viruses (NPV) are also common pathogens of the larvae of butterflies and moths. The virus invades many tissues in the insect including the blood, fat body and tissues outside the tracheae (breathing tubes). As infection progresses, larvae become sluggish and the skin discolors and may appear oily. Before dying, larvae will often climb to the highest point available. In death, their corpses hang from the food plant forming bags of liquified tissues which rupture, contaminating the food plant with millions of virus particles. Alfalfa looper is susceptible to virus infection and outbreaks of this insect are brought under control by the virus. Unfortunately, the virus does not kill the loopers until they are nearly mature and have done their damage. To overcome this commonly observed drawback with natural control, it may be necessary to artificially inoculate the population early in the season to increase the susceptibility of young larvae to disease.

Various types of fungi are insect parasites and can either kill insect hosts outright or reduce their ability to reproduce. In addition, infection will leave the insect weakened and susceptible to other disease causing organisms, such as bacteria, or to poisoning by insecticides. Fungi do not attack insects indiscriminately. The fungus, **Entomophaga grylli,** for instance, is known to attack certain pest grasshoppers. Another **Entomophaga** species attacks pea aphids. **Strongwellsea castrans** is a fungus which infects canola root flies and, as its name suggests, leaves the adult flies unable to reproduce normally.

Naturally occurring disease causing protozoa are numerous. Grasshoppers can become diseased by a single-celled protozoan, **Nosema locustae,** which occurs in trace levels over much of the grasshoppers' North American range. During grasshopper outbreaks, the pathogens also multiply and can reduce host populations to low levels. Infected grasshoppers eat less, produce fewer eggs per pod and lay fewer pods because the disease organisms compete with the grasshopper for the food reserves in its body.

Various programs have studied the potential of applying large doses of **Nosema** to grasshopper populations. Very large doses act like an insecticide and kill grasshoppers outright but leave other insects unharmed. Lower doses

reduce the grasshoppers' ability to reproduce, feed and move about. The effects of **Nosema** have been studied in combination with other natural enemies and with insecticides. The results show that **Nosema** will be a viable agent for control when integrated with other compatible grasshopper control agents.

Nematodes are also useful biocontrol agents. **Steinernema feltiae,** otherwise known as roundworm or eelworm, is a beneficial nematode. It is alerted to its prey by carbon dioxide and body heat. After entering the host's body, the tiny worm feeds on microorganisms it has introduced. Most hosts die of bacterial infection within days.

S. feltiae is microscopic. One drop of emulsion would deliver thousands of the parasites. It can be sprayed on, or mixed with water and poured on the ground to infect cutworms, armyworms, wireworms, click beetles, root worms, maggots and other pest insects. It is commercially available for greenhouses and indoor plantscapes.

Microbial insecticides

The table (reference 1) lists many naturally occurring insect pathogens which contribute substantially to suppression of some pest insects. These pathogens may normally cause a low level of infection, killing a small proportion of the pest population, or they may cause widespread infection (epizootics) resulting in high mortality and dramatic decline in pest numbers.

Cyclical abundance of certain pest species may be due largely to cyclical patterns of disease. For example, mortality from naturally occurring nuclear polyhedrosis virus (NPV) may be a major cause of rapid declines in populations of true armyworm. Similarly, a naturally occurring NPV infected as many as 65 per cent, but usually less than 10 per cent, of bertha armyworm larvae collected in a survey of canola fields in Manitoba. The virus probably contributes to regulation of populations of this important pest.

There is great potential in using pathogenic microorganisms to control pest insect populations. At present, various commercial formulations of **Bacillus thuringiensis (B.t.)** are widely used in Canada against insect pests of forestry and agriculture. Two viruses are registered for use against forest pests, but they are not yet widely used.

The use of **B.t.** in forestry has grown steadily: 27,000 ha of budworm-infested forests were treated with **B.t.** in Canada in 1979, and in 1986, planned forestry operations

Reference 1:

Insect pathogens which are potentially useful in integrated management of insect pests of Canadian agricultural crops.

Pathogen	Target Insect	Crop	Pathogen	Target Insect	Crop
Bacteria			Fungi		
Bacillus thuringiensis	Cabbage looper, imported cabbageworm, diamondback moth	Crucifers, rutabaga	Aschersonia spp.	Greenhouse whitefly	Greenhouse tomato, cucumber
	Cabbage looper	Tomato, celery, spinach	Beauveria bassiana	Codling moth	Apple
				Colorado potato beetle	Potato
	Leafrollers, etc.	Apple	Entomophthora grylli	Grasshoppers	Cereals, rangeland
	Tobacco hornworm	Tobacco	Metarrhizium anisopliae	Various insects	
	European corn borer	Sweet corn	Verticillium lecanii	Greenhouse whitefly, aphids	Greenhouse tomato, cucumber
	Indian meal moth	Stored wheat, potato			
Bacillus thuringiensis with Beta-exotoxin	Colorado potato beetle	Potato, tomato	Zoophthora phytonomi	Alfalfa weevil	Alfalfa, clover
Viruses			Zoophthora aphidis	Aphids	Potato, peas, etc.
Cydia pomonella GV	Codling moth	Apple	Microsporidia		
Euxoa messoria NPV	Dark-sided cutworm	Tobacco	Nosema locustae	Grasshoppers	Cereals, rangeland
Mamestra configurata NPV	Bertha armyworm	Canola	Nosema pyraustae	European corn borer	Corn
Pieris rapae GV	Imported cabbageworm	Crucifers	Vairimorpha necatrix	Cabbage looper, European corn borer, etc.	Crucifers, corn, etc.
Pseudaletia unipuncta NPV	Fall armyworm	Cereals	Nematodes		
Trichoplusia ni NPV (and Autographa californica NPV)	Cabbage looper	Crucifers	Steinernema feltiae	Corn rootworms	Corn
				Root maggots	Crucifers, carrot
	Alfalfa looper			Cutworms	Cereals, crucifers

were to have sprayed more than 1.4 million hectares. On the other hand, chemical pesticide use for budworm infestation has simultaneously declined from 99 per cent in 1979 to 26 per cent in 1986. Reliance on chemical pesticides alone in forestry is no longer economical, rational or publicly acceptable. In contrast, microbial insecticide use in agriculture was nearly static between 1980 and 1984 but increased dramatically in 1985 as can be seen from the table below (reference 2).

The static use pattern in agriculture during the early 1980s is surprising considering that **B.t.** is recommended by most provinces for several pests of field and horticultural crops. Half of the **B.t.** manufactured in North America is used in agriculture, but in Canada, as can be seen in the table above, only 5.7%, 1.2% and 3.6% of the total **B.t.** imported in 1983, 1984 and 1985 respectively, was for agricultural use.

At present, **B.t.** is the only microbial insecticide registered for use on agricultural crops in Canada. Several formulations of **B.t.** are registered in Canada for commercial and domestic agricultural use. Among the registered uses of **B.t.** are: cabbage looper, cabbageworm and diamondback moth on cruciferous crops (including canola, cabbage and rutabaga); and cabbage looper on celery, lettuce, spinach and tomato. More than half of the cruciferous crops grown in Ontario (about 4,000 ha in 1983) were sprayed at least once with **B.t.** in 1984. Yet despite the effectiveness of **B.t.** against these pests (comparable to that of chemical insecticides), formulations of the bacterium are not used as extensively in other provinces as they are in Ontario.

An increase in range of insects susceptible to **B.t.** can be obtained by modifying the formulation. **Bacillus thuringiensis** is a spore-forming bacterium that produces a crystal of toxic protein (called delta-endotoxin) during the spore-forming process. A similar protein, beta-exotoxin, has been included in new formulations for Colorado potato beetle control. These formulations, containing the exotoxin, are not registered in Canada.

Several unregistered insect viruses have particular potential in agricultural pest management systems. The granulosis virus (GV) of codling moth, a major pest in Canadian apple and pear orchards, is of vital interest for commercial development as a microbial insecticide for management of codling moth. The virus is specific for codling moth and does not affect other insects in the orchard. Achieving economical mass production of codling moth GV has been a major problem in its commercial development.

The fungus, **Verticillium lecani,** has been extensively tested in Ontario, Alberta and British Columbia for control of greenhouse whitefly and aphids on cucumbers, tomatoes and greenhouse chrysanthemums. The fungus is registered for those uses in the United Kingdom. Results of tests in Canada have been variable: control of aphids on greenhouse crops has been acceptable while control of other insects has not.

Several other pathogens, including bertha armyworm nuclear polyhedrosis virus (NPV), grasshopper microsporidium **Nosema locustae,** and nematode **Steinernema feltiae,** are known to be potentially useful in integrated pest management systems.

Vertebrate predators

Domestic birds - Flocks of poultry, especially turkeys, are helpful against climbing cutworm, armyworm, and even grasshopper infestations, with the added benefit that little additional food should be necessary for the turkeys that season. In California, from 175,000 to 200,000 domestic geese are used each year to control insects and grassy annual and perennial weeds in fields of cotton and various other crops. The use of geese has been a method of controlling weeds in strawberries for many years. Chicken ranchers near Riverside, California use young male chicks to control flies around the cages of laying hens.

Wild birds - Wild birds are also extremely beneficial in insect control. A study done by the United States Department of Agriculture found that enormous numbers of harmful insects were eliminated by birds and that the diets of some of our most common birds - such as swallows, house wrens, kingbirds, phoebes - are 90 to 100 per cent insect. The American study determined the percentage of seeds, fruits and insects in the diets of birds. But the numbers of insects consumed are also important. For example, a chickadee can eat up to 4,000 insect eggs a day; a wren family feeding its young will consume more than a thousand insects a day; a tree swallow will eat 2,000 to 3,000 mosquitoes a day. Also birds are at the height of their feeding activity from March to late July - exactly the period when the farmer needs help.

Reference 2:

Units[1] of **B.t.** shipped to Canada between 1980 and 1985.

Year	Forestry Use	Agricultural Use	% for Agriculture
1980	86,000	8000	8.5
1981	6,800	7350	51.9
1982	71,300	8240	10.3
1983	134,000	8100	5.7
1984	633,000	8000	1.2
1985	1,546,376	58224	3.6

1 Unit = 16 billion international units of potency.

In order to have the on-going pest control that is provided by birds, the farmer should provide habitat, such as areas of tall grass, bushes and trees (necessary for nesting and for protection from enemies) and plantings of seed bearing trees or bushes for a continual food source. A source of water is also necessary. Undisturbed grass is important. It is not usually realized that many of our most beneficial birds nest on the ground (in undisturbed grass) or just a few inches above the ground (in woody plants) and also feed on the ground. Thus an effort should be made to provide not just tall trees, but bush and grass as well. The grass should be left undisturbed until late July, when young birds have fledged.

Other vertebrates - It has become customary for farmers to look upon rodents and other small mammals as pests, but these animals are very helpful in insect control.

Moles and shrews destroy great numbers of soil inhabiting insects, principally white grubs and cutworms of various kinds. Studies done at the end of an outbreak of larch sawfly in the Maritimes, showed that predators had destroyed 48 per cent of the sawfly cocoons. (The insect pupates in the ground and forest litter.) Small mammals caused half the mortality and insect predators the remainder. In areas where sawfly cocoons have been abundant for several years, 40 to 50 per cent of the cocoons are generally destroyed by small mammals; in one area of New Brunswick, 80 per cent of sawfly cocoons were destroyed.

Nocturnal webworm, cutworm and armyworm moths are subject to predation from a very efficient night-flying insect predator, the bat. Bat populations have largely declined, unfortunately for the farmer. Recent studies of a huge bat colony in Southern Texas showed that bats ate 250,000 pounds of insects each night!

Toads, frogs, salamanders and lizards are often overlooked as insect predators, as are mice and skunks. Examinations of the droppings of skunks have shown that 85 per cent of their food consisted of range caterpillar pupae. Similar figures occur for other small to medium sized mammals.

Modern farming has created pests by establishing monocultures and by eliminating wildlife. Complete dependence on chemicals for insect control is not a sound policy. Future pest management practices will rely on a variety of methods.

Classical biological control

Classical biological control is the regulation of a pest population (insect, mite, weed, disease or mammal) by exotic (imported) natural enemies. Usually, the pest species is itself an exotic that has reached higher population densities in the new environment because of conditions more favorable than in its area of origin. The favorable conditions may include a lack of natural enemies capable of regulating the pest. By distributing and establishing native natural enemies a pest population can be reduced to noneconomic levels. Although this is a sound biological control tactic, it is not "classical" and is much older than the method of importing natural enemies to battle pests. For example, since ancient times, Chinese growers have placed nests of a predatory ant in citrus trees to control various leaf-feeding insects.

The first dramatic success in using an imported insect to control a pest insect was achieved in 1888 using an Australian lady beetle called the vedalia beetle. Within two years of bringing vedalia beetles into California, the citrus industry was saved from certain destruction by cottony cushion scale (a small sap sucking insect). Today, certain lady beetle species are reared in large numbers in insectaries for sale as "biocontrol agents".

Another example of classical biological control involved the citrus blackfly, an insect native to subtropical and tropical Asia. In Mexico, the citrus blackfly was found for the first time in 1935. It rapidly dispersed to citrus growing areas where it became an important pest. Several importations of natural enemies were made from Panama and Malasia, but control came later when several species at parasitic wasps were imported from Pakistan - Western India. Their early establishment stimulated the initiation of a collection and distribution program unequalled in magnitude by any other biological control project in the world. A special gasoline tax was levied to defray the main costs and at one time about 1,600 men were working on the project.

Closer to home, the alfalfa weevil was first discovered in the United States in Utah in 1904. Seven years later, the alfalfa weevil ichneumon, **Bathyplectes curculionis,** was imported from Italy. The weevil apparently migrated into Alberta from Montana where it had become established by 1930. The parasitic wasp, which feeds internally on the weevil larva in the same manner as the bertha armyworm ichneumon, was found in Alberta alfalfa fields shortly after the weevils were found here in 1954. The parasite is thought to have been one of the main factors keeping the weevil under control in Alberta.

Natural enemies, whether introduced or native, require proper management in order to be effective. Various management methods have been developed for natural enemies. Some of these are discussed in the next section.

Avoidance of harmful farming practices

Farmers with clear information about the natural enemies of a crop pest can attempt to provide the growing and overwintering conditions required by them. They can also avoid harmful farming methods. For instance, if the farmer knows that the pest overwinters in the soil (as eggs, or pupae, for example) and that the beneficial enemies of the pest overwinter in the crop trash, then burning or turning under the crop trash will likely free the crop pest from its enemies. The solution would be to leave the crop trash in place until spring.

Similarly, when crop pests are mobile and their enemies are not, then harvesting destroys the beneficial enemies while the pest insects simply move and infest another crop. In this case, strip harvesting is feasible. The crop is harvested in alternate strips. When some regrowth of

the harvested strips occurs, the final strips are harvested. This is particularly useful in alfalfa.

Cultural control is a valuable part of pest management, but certain methods such as plowing, disking, mowing and burning can be harmful to beneficial insects. The effects of such operations must be fully evaluated, and harmful ones eliminated or modified if at all possible. For example, burning or burial of surface litter, while beneficial for some diseases, weeds and insect problems, also destroys the habitat for overwintering populations of beneficial insects such as ladybugs. The individual farmer can only make a decision after a careful field scouting program.

Temporary habitat for birds can be maintained by not mowing grass or hay until after July 15 when most ground nesting birds have fledged their young.

Weed control practices have reduced the effectiveness of some parasitic flies and wasps. The elimination of host weeds plus the possible toxicity of herbicides to the insect parasites might cause an increase in crop damage. Complete abandonment of field edge weed control cannot be recommended, however, because faster growing weeds crowd out desirable species. To achieve the biological control potential of parasites that live there, a herbicide program must be developed which favors the continuous maintenance of field margin species.

In some instances the use of pesticides cannot be eliminated. If pesticides are in general use in the area, even if a farmer chooses not to use pesticides, his/her farm may be affected by their use. For these reasons a short section on protecting beneficial insects from pesticides is included here. The examples used are only indicative of the principles since local examples are not available.

Pesticides can interfere with the natural control of secondary (noneconomic) and primary pests. Organic and inorganic materials, ranging from stomach poisons to dormant oils, dusts, and contact insecticides can have adverse effects. One of the most striking cases is from California where DDT was used to control pests in 1946 and 1947. A ladybug, the vedalia beetle, had long provided outstanding biological control of cottony-cushion scale (a relative of aphids) on citrus. When DDT was introduced, the beneficial vedalia beetles were killed by the sprays, while cottony-cushion scales (the primary pest in the orchards) were not. Serious outbreaks of scale resulted.

A secondary pest, red-banded leaf roller, rose to economic levels after various organic insecticides were used against codling moth and other apple pests. In this case, too, the natural enemies of the pest were destroyed by pesticides.

Since most insecticides are quite toxic to insect predators and parasites as well as (or sometimes even more so than) the pests, it is important to consider ways to modify or eliminate pesticide treatments to minimize the effect on beneficial insects. There are at least two ways to use insecticides selectively in order to conserve natural enemies.

The first is to use an insecticide toxic only to certain insects. Many early insecticides were selective. The arsenicals, for example, killed insects with chewing mouthparts. Predators, parasites and insects with piercing-sucking mouthparts such as aphids and leafhoppers were not killed. The new synthetic organic insecticides kill insects through various combinations of contact, ingestion, and fumigant action. They are generally less selective, and predators, parasites and pollinators are more seriously affected. Even with newer insecticides, however, some selectivity exists. Systemic materials such as demeton (Systox) can be used to control harmful insects while preserving many beneficials. Once demeton is absorbed by plant foliage, it no longer kills by contact. Some short-lived materials, such as TEPP, are highly toxic to the active insect stage at the time of application. However, insect eggs and pupae, and transients such as pollinators not in the field during spraying, are frequently unaffected. Although chlorinated insecticides were at first considered to be effective against virtually all types of insects, it was later found that DDT, toxaphene, and several other chlorinated insecticides were quite selective. Toxaphene, for example, is not highly dangerous to honey bees. Several of the organophosphates can also be selective. Trichlorfon (Dylox) can be used to control lygus bugs and caterpillars with relatively little harmful effect on many predators and pollinators.

The second way insecticides can be made selective is by changing the application method. Such changes may take into account the activity patterns of insects - many insecticide labels now advise that spraying in the evening will lessen the impact on honeybees because most will have returned to their hives. Insects have food preferences which may be used to advantage. Wheat bran laced with insecticide or an insecticide/pathogen combination has been found to be very effective for grasshopper control. Not only do grasshoppers readily eat the poisoned bran bait but less chemical is needed to achieve the same control as spraying would provide. Beneficial insects are left unharmed.

Thus, timing of application, dosage and formulation can be modified for improved selectivity of even broad-spectrum pesticides. It should be pointed out, however, that altering use patterns does not insure that a pesticide will become favorably selective. A treatment that selects for desirable insects in one situation can be highly toxic to important natural enemies in another.

In deciding the amount of a pesticide to use consider the degree of pest control required to prevent economic loss, the potential for control by natural enemies or cultural methods, the need to maintain a reservoir of pests as food for natural enemies, and the conservation of natural enemies related to the entire crop/pest complex. A high level of control may be necessary for only a few key pests. High dosages may be required to overcome inadequate timing, coverage, or developing resistance. Dosage and timing cannot be separated in many cases, because as

dosages are reduced to achieve selectivity, it is usually necessary to compensate for the reduced killing power with improved timing. Reduced dosages are commonly used for immature stages of insect pests - common grasshopper chemicals may be registered for application at one-third to two-thirds of the adult rate. Applying these reduced dosages at the wrong time, that is, when most of the population has reached the adult stage, will produce poor results. Information on optional spray timing is crucial to any pest management program and is available for prairie farmers. Spring pesticide applications for economic populations of grasshoppers are less expensive and have fewer adverse effects on natural enemies, because many are not active or exposed to pesticides at that time. Applying sprays so that they cause minimum harm to beneficials is especially important when using broad-spectrum, highly toxic insecticides. In alfalfa pest management programs, the only practical way of using carbofuran, for instance, may be to apply it very early in the spring when alfalfa first starts to grow, or to the stubble following harvest of the first hay crop.

The amount of pesticide to use in a management program can be based on the degree of pest control required to prevent economic loss. Other considerations are the readiness with which the pest can be controlled by natural enemies or food destruction by cultural methods, the need to maintain a reservoir of pests as food for natural enemies, and the conservation of natural enemies related to the entire crop/pest complex. A high level of control may be necessary for a few key pests only. The use of high dosages to overcome inadequacy of timing or coverage should be avoided.

The farmer interested in stabilizing an insect pest problem should manage the enemies as well as the pests. A mixed farm habitat, with a blend of cropland in rotation, pasture, woods, some wetland and other natural areas, encourages a diversity of species. If the terrain is not varied, then shelterbelts, hedgerows, and some permanent grass areas in headlands and near water sources will help to provide the habitat needed to encourage predators and parasites of insects.

The maintenance of a diverse plant community may provide needed hosts, sources of food, overwintering sites, and refuges from predators. There is a general relationship between diversity and stability in nature.

Natural wild flowering plants and grasses, along with trees and bushes should be maintained in areas surrounding the crop unless one is sure that their beneficial effects can be replaced by some other measures. Plantings of native wild flowers and grasses are especially beneficial since there are adapted to our climate and growing conditions; they have natural enemies (and thus are "stable"), and they provide a season-long source of pollen and nectar for beneficial insects.

So-called waste or wild areas need not be altered, cultivated or controlled, as long as they are not dominated by a weed or insect pest. Some tolerance of low levels of pests is advised because without pests, there will not be a breeding area for natural enemies.

Provision of food and shelter for natural enemies of insect pests

To a large extent, the maintenance of diverse plantings on the farm will help provide food and shelter for beneficials. But there are some particularly helpful practices which aid the predators and parasites of insects. One is to provide a plentiful and continuous source of pollen. Studies have shown that there was greater parasitism of tent caterpillar eggs and pupae and codling moth larvae in Ontario orchards that were unsprayed and had many nectar producing flowers, compared with orchards containing few flowers. In California, a predatory mite controlled the avocado brown mite when pollen was dusted on the plants, but did not control the pest when pollen was omitted. Thus the planting or maintenance of native wildflowers and grasses can be beneficial to the predators and parasites of pest insects. Vegetables and weeds of the parsley family are particularly useful for attracting beneficial insects. Flowers of carrots, anise, dill, parsley, coriander, parsnips and wild parsnips attract beneficial wasps. Willow trees provide an early source of pollen in the spring.

As well as pollen-producing flowers, plantings of seed and berry producing trees and bushes are helpful. Currant bushes, Nanking cherry bushes, crabapple trees, Manitoba Maple or Mountain Ash trees, caragana hedges, all provide protective cover and food for insects, small mammals and birds. Nesting sites and drinking water, bushes and undisturbed grass can encourage the build-up of a bird population.

It is also possible to provide artificial food and shelter for beneficials. Although it is not yet common practice, some agrologists are using artificial food supplements sprayed on crops to encourage the population growth of beneficial insects. These sprays are often sugar or molasses based. Artificial shelters can be provided for bats and birds. Bats help control night flying moths, such as the cutworm moth, which have few other predators. The little brown bat, native to Alberta, can be enticed to roost in artificial shelters near a water supply. (It may take the bats several years to accept the shelter). Bird boxes will boost the bird population. The right type, size and dimension of bird box should be used since birds have varied needs in housing. Most government wildlife departments have information on shelters and houses for birds and bats.

Field scouting

Before developing a control strategy, get familiar with the kinds and numbers of pests in a field and their stage of growth in comparison with the crop. Do this by walking each field and doing random counts of each pest species. Knowing the pests present allows for specific control measures to be planned and implemented. Be sure you can identify your weeds in all of their growth stages.

FREQUENCY

Scouting should be done weekly when pests are present. Some fields should be checked daily when infestations are approaching economic levels. If there are no signs of pests, don't waste time with detailed counts. With practice, you will soon become efficient at scouting pest populations.

SAMPLING PATTERNS

The purpose of sampling is to get a representative, objective assessment of pest density or damage throughout an entire field, not just the edge, centre, high or low area. Do not isolate an obviously damaged area in the field, or take one sample and make a decision. Damage may be isolated on a hill, margin or low spot and controls need not be applied to the entire field. If 5 per cent of the field is infested and there is a 50 per cent loss of yield in that infested part, how should control be applied? Consider a quarter section infested with diamondback moth:

A 5% infestation on 160 acres = 8 acres infested
8 acres x 50% (30 bu/ac yield) = 120 bushels lost
120 bushels x $6.50/bushel = $780 lost to insects
Cost of treating 160 acres at $8/acre = $1,280

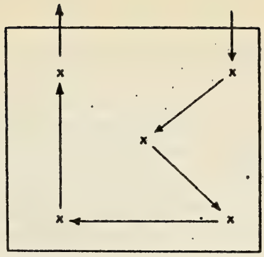
Treating the entire quarter section will cost $500 more than the loss due to the insect damage.

There are three basic sampling patterns for field crop pests. The pattern followed depends upon the pest because each species behaves differently.

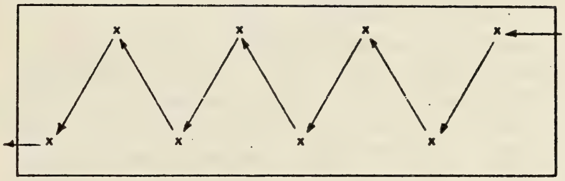
Pattern I

Pest or disease expected to be randomly spread throughout the field.

When sampling for a pest with this distribution, the sample sites are evenly distributed over the field, excluding obvious influencing factors such as field edges (sample at least 10 m in from the edge), hills, and solonetzic soils. In a square field, this might mean one sample in each corner and one in the centre, or a zig zag design in a long narrow field.

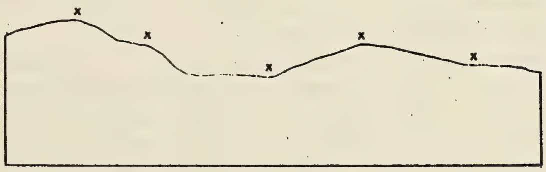


Pests fitting this pattern are:
stinkweed, wild oats, leaf diseases,
aphids, diamondback moth
and bertha armyworm.



Pattern II

Pests or disease expected to be concentrated in particular areas of a field. These pests are usually associated with high or low spots or other distinguishable features of the field. If pests are found in one area and not in others, more samples should be taken around the initial find to determine the extent and severity of the problem more accurately. This holds true for all sampling patterns.



Profile of Field (Side View)

Examples: redbacked and pale western cutworms, thistles, quack grass, root rot, damping off.

Pattern III

For pests expected to appear at field edges first, samply by walking the field edges, fence lines or ditches.

Examples: flea beetles, grasshoppers, scentless chamomile, thistles.

In some instances it is necessary to combine two or more patterns. Do this when the field is uniform, when little is known about the pest, or when a control decision is being contemplated but you are not confident in the sampling program. At least one insect pest changes its pattern of invasion depending on the weather. Flea beetles usually invade the whole field by flying during warm weather but invade only in stages (by hopping from headlands) during cool weather (below about 18 °C). The more thorough the sampling, the more sound the decision, and perhaps the more money you will save.

SAMPLE SIZE

The number of samples required is based on variability in the distribution of the pest. For bertha armyworm, the required number of samples and numbers of larvae per sample are shown in the insect control section under bertha army worm. With some other insect pests we have an idea of the number required to cause economic damage, but relatively few economic thresholds have been derived scientifically. As with diseases and weeds, the distribution of the infestation may depend on previous cropping patterns.

BASIC EQUIPMENT

Sample kit - The following items will be useful for fast and accurate sampling and should be assembled as a kit for field use:

- clip board
- tweezers
- hand trowel
- paper bags
- pocket knife
- shovel
- vials
- record sheets
- 10x hand lens
- alcohol
- clear plastic bags
- sampling frame (1/4 square metre)
- sweep net
- pests identification publications

Detection and accurate identification of a pest is a vital component of prevention. When diagnosing a problem, it is important to consider all of the possible factors that affect the severity of the disease including weather, fertilizers and herbicides. Obvious problems are easy to detect; however, plant disease frequently may not have obvious causal agents. Very close examination and perhaps laboratory culturing may be required.

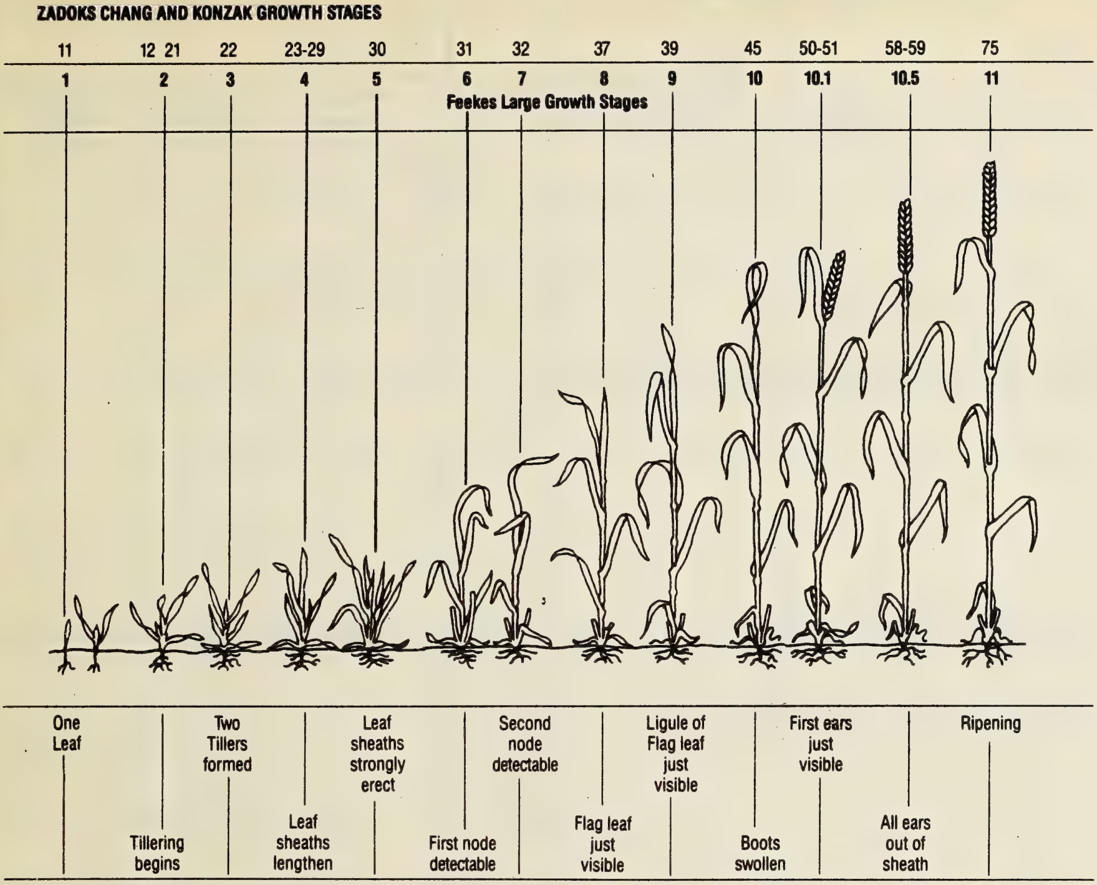
Basic scouting techniques for diseases are as follows:
- Seedlings: Dig up affected plants and examine the roots and stems for lesions or rots.
- Leaf diseases: Examine all leaves on the plant for any sign of damage. Foliage damage causes greatest losses in the seedling or flowering stage of plant growth; it is of much less consequence when seed or grain is maturing.
- Stems and heads: These should be examined closely for signs of fungal material or lesions. The stems, pods or heads should be split or taken apart and examined for discoloration caused by fungi or bacteria.

The Feekes and Zadoks scales are used to identify stages of cereal crop developent. The time at which sampling for certain diseases should be conducted are often identified by these scales.

The Feekes scale of growth stages was developed for wheat but applies equally to barley up to the boot stage. Completion of stage 1 will require about 6-12 days, and stages 2-5 an additional 5 or 6 weeks. Damage to growing parts of the plant during the seedling stage prevents normal growth, and weak seedlings do not grow into healthy plants even under ideal growing conditions. However, the growing point remains below the soil surface until tillering is nearly complete. This delayed emergence of the growing point protects it from damage by frost, wind, hail and some insects, and allows plant recovery if the leaves are damaged. Damage to leaf tissue at this early stage has little or no direct effect on yield, however, some maturity delay is likely.

Stages 6 to 10 proceed very quickly in late June or early July, and flowering in barley takes place in the boot at our latitudes. Grain filling and maturity will be completed during August over most of the province.

The Feekes scale of growth showing the development stages in a cereal plant.



FIELD RECORD FORM

Field **Acres**

Weed Control

Year	Crop	Variety	Seed Treatment	Seeding Date	Tillage Operation	Date	Problem Weeds	No. Per m^2	Treatment
19 ___									
	Notes								
19 ___									
	Notes								
19 ___									
	Notes								
19 ___									
	Notes								
19 ___									
	Notes								

FIELD RECORD FORM

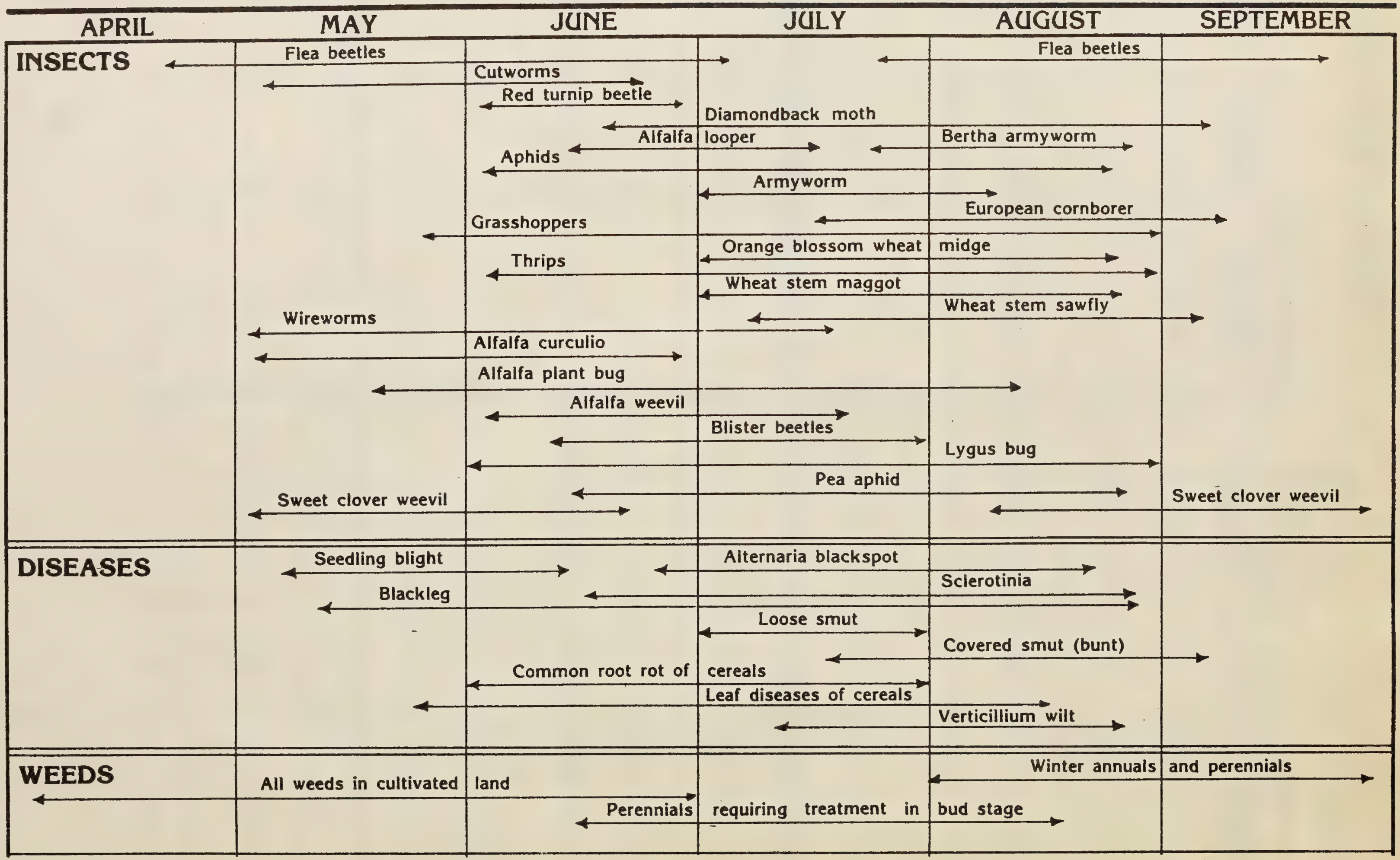
nsect Control

Problem Insects	No. Per Unit	Treatment

Disease Control

Diseases Identified	Level of Infection	Treatment

FIELD SCOUTING TIMETABLE



NOTES

WEED CONTROL

Index

General

An effective weed control program integrates many methods. Planning is required to achieve optimum weed control at minimal cost. Considerations are:

- the availability of equipment and labor
- the types of weeds present
- the soil type
- the extent of the infestation
- the cropping system
- other environmental conditions

Since these factors are not always predictable, the strategy must be flexible. This section describes general principles of weed control, followed by guidelines for control of specific weeds.

Weed biology

Understanding the biology of weeds is critical in developing control strategies. The main strategies in controlling annual weeds are to prevent seed production and reduce the number of weed seeds existing in the soil. With perennials, destruction of the root system is the key. Nonchemical weed control techniques exploit the biological differences between the crop and the weed and are accomplished through cropping and tillage practices.

Life cycles and control strategies- Plants are grouped by life cycle there are annuals, biennials or perennials.

Annuals - There are two types of annual weeds. Summer annuals germinate in the spring, produce seed during late summer or fall, and then die. Examples are wild oats, kochia and green foxtail. Winter annuals germinate in late summer or fall, producing rosettes which overwinter and continue growth early the following spring. Seeds are produced in the early summer. Examples are stinkweed, flixweed and shepherd's-purse. Some weeds are both winter and summer annuals. Since annual weeds reproduce only by seeds, control is simple. Kill the plants before seed production occurs and encourage seed germination when the seedling weeds can be easily destroyed without interfering with crop production. This strategy can be thwarted by the tendency of these weeds to grow and mature very quickly. Winter annuals often flower even before all the spring snow is gone. The life cycle of annual weeds is similar to that of annual crops: they germinate, grow and produce seed along with the crop.

Control recommendations are:

- Till between rows of vegetable crops.
- Give a severe harrowing or a shallow rod weeding when weeds emerge before the crop.
- Use preseeding tillage to get annual weeds to germinate before seeding.
- Rotate the land to perennial crops.

Biennials - These weeds require between 12 and 24 months to complete their life cycle. In the first year a taproot and foliage are produced. The root survives the winter and in the spring the shoot bolts, producing flowers and seeds. Biennials are controlled by fall or spring tillage. With increased production of fall sown crops and reduced tillage, biennial weed populations have increased. Example are scentless chamomile, stork's-bill, and narrow-leaved hawk's-beard. Biennials can also be a problem in perennial forage crops, or anywhere tillage cannot be used.

Perennials - These weeds persist for more than two years and have either fleshy tap roots, as in dandelions, or creeping root systems, as in Canada thistle. Both root systems store food throughout the season. Fleshy rooted perennials reproduce mainly by seed. Creeping rooted perennials grow in patches and spread both by seed and roots.

Perennial root systems

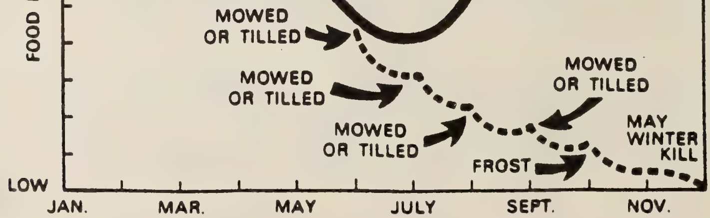
Fleshy tap root
(e.g. dandelion)

Lateral creeping roots
(e.g. Canada Thistle)

Perennial weeds are less of a problem when fallow is included in the rotation than when annual crops are grown continuously. Under continuous cropping, creeping rooted perennial weeds, like Canada thistle, perennial sow-thistle, quack grass and toadflax, become problems. These weeds can also be problems in weak perennial crops. To control perennial weeds two possible strategies can be implemented: 1) prevent seed production and 2) deplete the food reserves in the roots. Repeated mowing and/or cultivation may help to achieve this.

Occasional light tillage will break up and scatter root pieces producing new infestations. Intensive tillage or mowing throughout a season will strain the root energy reserves. Timing of tillage is critical. Food reserves are generally low from the end of May until mid-July. Starting to till or mow at the end of May will cause new shoots to emerge from dormant buds and the stand will appear thicker. This flush of new growth uses more energy than it produces so the overall food reserves are diminished. After three to four weeks, the weed stand should be mowed or tilled again, further depleting the root reserves. Weed control is accomplished by the gradual starving of the root system. The effect of repeated tillage or mowing every three to four weeks until frost can be seen in the following diagram.

EFFECT OF MOWING OR TILLAGE ON ROOT RESERVES



Graph shows the effect of timely mowing or tilling on root reserves as compared with unmowed thistle plant (from Klingman).

Fleshy rooted perennials can be controlled by tillage. When the tap root is cut off, the top growth will starve. Controlling fleshy rooted perennial weeds is difficult in perennial crops. Often the only option is to plow the crop. Summerfallow or annual crops should follow until the weeds are controlled. Control of perennials on roadsides is usually limited to mowing or spraying. Perennial weeds in pasture may be controlled by mowing and grazing. Sheep and goats will utilize weeds as browse. If only cattle are grazed it is important not to give the weeds a competitive advantage by overgrazing. Rotational grazing systems should be helpful.

Time of germination - Germination of weed seeds is influenced by temperature, moisture, depth of burial and dormancy of the seed. Knowing the date of the expected emergence is helpful in timing cultivation, seeding, and spraying. Dates, where available, are given in the individual weed section.

Time of flowering - Knowing the approximate time of year that a weed flowers enables one to control the weed or harvest the crop before viable seed is produced. Viable seeds are produced at varying stages of plant maturity, depending on the species.

Germination of weed seeds cut at various stages of maturity

	Cut in bud stage	Cut when in flower	Cut when dead ripe
	percent germination		
Sow thistle	0	100	100
Groundsel, common	0	35	90
Dandelion	0	0	91
Canada thistle	0	0	38

* Sow thistle seeds are viable when the weed is in flower. No viable seeds were detected when Canada thistle or dandelion plants were cut at that stage.

Seed dormancy - Dormancy is the characteristic of weed seeds which enables them to survive for long periods in the soil without germinating. Weed seeds in the primary dormant state can remain alive in the soil and even though conditions of temperature, moisture, etc., are ideal, they do not germinate. Dormancy is broken naturally by the effects of microorganisms, acids, salts, alternate freezing and thawing, and drying-wetting cycles.

The length of time seeds remain alive in the soil is called seed longevity. Longevity of weed seeds varies with species. Knowing the longevity assists in planning crop rotations. For example, green foxtail seeds live for one to four years. A perennial forage crop grown for four years would deplete green foxtail seed reserves. Proper weed control measures must be carried out to prevent reinfestation of the soil.

Weed - crop interactions - New weed problems evolve along with new crops and new cropping practices. For example, there has been an increase in winter annual weeds in winter wheat production. Without fall tillage winter annual weeds proliferate. Perennial weed populations have increased under continuous cropping systems without tillage, perennial root systems become well established.

The farmers' defense is to continue rotating the crops grown on a parcel of land to prevent the build-up of weeds specifically adapted to one type of crop. Crop rotation implies shifting between cereals, row crops, perennial forages and winter annual crops in a predetermined manner. Volunteer crops are weeds since they compete with the seeded crop and reduce yields. Newly fallen crop seed can usually be encouraged to germinate by shallow fall or spring tillage. In a dry fall seed is best left on or near the soil surface, exposed to the elements. In spring, surviving seed can be stimulated to germinate by tillage. A second tillage with or just before seeding will destroy most of the volunteer crop seedlings.

Choosing weed control measures

Weed control, particularly if chemicals are not used, requires planning. It is difficult to plan nonchemical strategies for controlling specific weeds, without interfering with the control of other weeds, insects, or plant diseases. Conflicts in recommendations must be recognized and priority given to controlling pests of main concern.

ECONOMICS

Economic threshold densities are defined as weed densities at which the cost of weed control equals the cash return from the recovered crop yield loss. This implies that there will be times when control of weeds may not pay. To estimate whether or not control is economical in a particular growing season, a number of questions need to be answered.

- **The extent of and species involved in the weed infestation?**
  Estimate this by walking the field and randomly counting and identifying the weeds present. The more counts made, the more accurate will be the estimation. This approach is most meaningful where strong competitors such as Canada thistle and wild oats predominate.
- **What is the likely crop yield loss caused by the weeds?**
  Crop yield losses caused by some weeds are known and are given under the individual weed listings in this publication. Estimates on yield losses from other weeds can be made based on past weed problems.
- **What is the cost of the weed control measures?**
  Calculate these costs including fuel, labor, equipment costs, additional seed costs, yield loss caused by delayed seeding or extra tillage, etc.
- **How much of the lost yield will be recovered following control of weeds?**
  This varies with the timing and method of control, the kind of crop, growing conditions and effectiveness of control. On average, assume about 85 per cent of the lost yield is recovered when a control method is implemented.
- **What is the market price of the crop?**
  The market price of the crop is an important factor in determining the economics of controlling weeds. The higher the market price, the greater the likelihood that weed control will be economical.
- **What is the expected weed - free crop yield?**
  This varies with soil type and fertility and climatic factors. Average yields for crops are available for the different soil zones in the province. Records from previous years will help in predicting yields. As with the market price of the crop, the higher the expected yield, the greater the likelihood that weed control will pay for itself. The crop stand and the time of emergence of the weed compared with the crop, should be considered in the economics of weed control. If the weeds get ahead of the crop, a greater yield loss can be expected than if the weeds emerge after the crop.

  Late flushes of weeds like green foxtail and stinkweed usually have minimal effects on the yield of competitive crops such as barley, wheat and canola. When the crop stand is poor, weeds cause greater yield losses.
- **What is the anticipated use of the crop?**
  In certain instances where the crop will be used for hay, silage or feed, the presence of some weeds may not be detrimental. It is even possible the weeds can be beneficial. In other cases the presence of even a few weeds may degrade the crop or make it unsaleable. The choice of crop for each field is thus very important in determining the losses a particular weed will cause. The presence of a weed which is locally prevalent may not be viewed as serious if the crop is being used for feed or is being delivered into the grains handling system. That same weed can make pedigreed seed or forage crops unsaleable to other regions not currently infested by that weed species. Having a local market for your crop makes a difference as to how much and which species of weeds are tolerable.

SOIL & WATER CONSERVATION

Several weed control practices can cause soil related problems, such as breakdown of soil structure, erosion, and/or loss of soil moisture. Tillage and summerfallow should be kept to the required minimum, owing to their potentially negative effects. Green manure crops can improve soil tilth and water holding capacity and may be used to compensate for the effects of tillage.

- **Loss of soil moisture** - Tillage causes moisture loss that leads to a reduction in yield. Yield losses caused by uncontrolled weeds must be weighed against the potential yield losses caused by moisture reduction from excess tillage. Loss of soil moisture in dry areas is of greatest concern. In these cases, tillage for weed control may not be feasible and other alternatives should be considered.

  One way of compensating for moisture loss is to increase moisture by managing winter snowfall (which constitutes 25 per cent of yearly prairie moisture). The use of standing straw strips for snow trapping is an effective means of increasing soil moisture in the spring.
- **Erosion** - Tillage operations that incorporate trash may leave soil exposed to wind and water erosion. To minimize this, leave some plant residue on the soil surface over winter. Effective weed control with minimal trash disturbance can be obtained with a heavy duty or wide blade cultivator, or a rod weeder.

Summerfallow fields are particularly susceptible to erosion. Working fallow should be kept to the minimum. Alternate strips of crop and fallow will help to minimize erosion. These strips should run at right angles to the prevailing winds. Green manure can be grown to maintain soil organic content as well as reduce erosion. Shelterbelts will also help reduce wind erosion.

- **Maintaining organic matter** - The organic matter content of soils decreases with cultivation. Organic matter maintains soil structure and reduces the potential for soil erosion.

  To maintain or increase the organic matter content of a soil, keep tillage to a minimum during the summer-fallowed year. Fibrous rooted plants, such as perennial grasses, can be planted to contribute to soil organic matter. Green manure crops, continuous cropping rotations and increased levels of fertility will also help to build organic matter.

Weed management in specific crops

CEREALS

Spring wheat and barley - Weed populations may be kept low by destroying as many weeds as possible prior to seeding. Early spring tillage will destroy overwintering stages of winter annuals as well as early germinating annual and perennial seedlings. This early tillage also aerates and warms the soil and brings new seed near the surface. This will stimulate germination of a second growth of weeds which may be killed at or during seeding. Packing, shallow seeding (into moist soil) and banding fertilizer will establish a competitive crop. Higher than normal seeding rates in heavily infested fields will be helpful in increasing crop competition. The use of clean, plump, disease-free seed also increases crop vigor.

Post-seeding tillage can be used on cereals in some areas of the province.

Late fall tillage destroys rosettes of winter annual weeds. If this is not feasible, 2,4-D can be used. Early fall tillage encourages germination of some weed seeds. Fall tillage severs perennial weeds and exposes the roots of these perennials to freezing and thawing, ultimately causing the deterioration of the root system.

Swathing the crop rather than straight combining is useful if late season weeds can be cut before they mature seed. After harvest a light tillage will increase weed germination if there is enough moisture. Annual weeds will be winter killed. Winter annual weeds that germinate in the fall will require either another late fall tillage, fall spraying, or an early spring tillage.

Winter wheat and fall rye - Weed control prior to establishing these crops is critical. Shallow preseeding tillage destroys weed seedlings. Winter annual weeds cannot be controlled through tillage, without injuring the crop, but some species may be selectively controlled with herbicides. (See **Guide to Crop Protection - Part I**).

Winter wheat and fall rye must be well established before freeze-up to avoid winter kill. Crops that overwinter poorly are extremely weedy the next spring since they have little competitive ability. On the whole few weeds can compete with a good crop of fall rye or winter wheat.

OILSEEDS

Canola and mustard - Cultural weed control in these crops is important since herbicides are not always available as alternatives. These crops should not be grown where perennial weeds are a severe problem. Preseeding tillage destroys existing winter annual and grassy annual weeds.

The ability of oilseeds to compete with weeds can be increased by encouraging rapid emergence. This can be done by shallow, uniform seeding. Packing ensures good seed-to-soil contact and prevents excess moisture loss. Canola and mustard are quite competitive with weeds once they get past the seedling stage.

Flax - Flax is a poor competitor. Many weeds in flax cannot be controlled with herbicides. For these reasons **it is important to seed flax on clean land.**

Early, shallow spring tillage should be followed two to three weeks later by a combined tillage, seeding and packing operation. This controls weeds and provides a firm seedbed. Increasing seeding rates by up to 25 per cent, can improve flax yields in competition with wild buckwheat. Many herbicides are also available for wild buckwheat control in flax. As broadcast fertilizer applications benefit weeds as well as the crop, fertilizers should be banded for maximum effect.

Sunflowers - Sunflower seedlings are sensitive to competition, especially from perennial weeds. The main yield reductions are caused by competition four to six weeks after seeding. Land seeded to sunflowers must be clean, since the crop is planted very early which does not always allow for early cultural control.

Harrowing can be done from time of seeding and occasionally even after crop emergence. A flexible tine-harrow causes less damage to shoots than a spike-tooth harrow. Postemergent harrowing controls annual weeds and perennial weed seedlings. It can be performed from the time the crop seedlings have two true leaves (the cotyledon "leaves" plus the first true set of leaves) until they are 15 cm tall. Harrowing works best on warm days when the sunflower plants are slightly wilted. Work across the crop rows. One harrowing reduces the plant stand by 7,400 to 12,000 plants/ha (3,000 to 5,000 plants/acre). Increase the seeding rate to compensate for this damage. Injury to sunflower roots from harrowing may increase the incidence of soil-borne root diseases.

FORAGES

Established perennial forages are good competitiors. However, as seedlings they are susceptible to competition from weeds. Forage crop establishment and maintentance are the keys to producing competitive stands.

To ensure a competitive crop stand, clean seed should be sown on relatively weed-free land. Seed should be planted into a firm, well-prepared seedbed at the recommended rate and depth. Seeding is best done in the spring when moisture conditions are favorable.

Campanion crops should be used where soil erosion or crusting are problems. Although companion crops suppress weeds, they also suppress forage seedlings and yield in subsequent years. Reduce seeding rates of cereals or flax when companion cropping is necessary; both methods will minimize the competition from the annual crop.

Mow companion crops at a height just above the forage seedling. This prevents smothering of forage seedlings and reduces weed seed set. Once established, forage crops will squeeze out most annual weeds. Old forage stands should be rejuvenated by fertilizing, reducing grazing or cutting, or applying appropriate herbicides. If these methods are ineffective then the stand should be worked down.

PULSE CROPS

Weeds compete fiercely with pulse crops. Pulse crop losses of up to 85 per cent have been attributed to weeds. For this reason pulses must be seeded into practically weed-free land. Field beans are generally seeded in rows so inter-row cultivation is possible. Fababeans and peas are usually solid seeded, however there is no inherent reason why they could not be row cropped. Harrows or a rod weeder can be used at shallow depths to control weeds after crop seeding but prior to emergence. Do not harrow at or following emergence of pulses.

BLADDER CAMPION

Silene vulgaris (Moench)

Life cycle - A tap rooted perennial spreading by seed and severed root pieces.

Emergence - Seedlings emerge from shallow depths throughout the growing season.

Flowering - Flowers from mid-June through fall.

Reproduction - Seed - The main method of spread is by seed. Large quantities of seed are produced from mid-July through fall. Seed remains viable in the soil for many years.

Vegetative -Reproduction from root pieces and severed crown pieces are the secondary means of reproduction.

Competition - Bladder campion prefers undisturbed areas so it proliferates in perennial crops. Badly infested perennial crops should be worked and put into annual crops, well tilled for two or more seasons. Bladder campion does not compete well in healthy, cultivated crop stands.

Management Strategy - Preventing seed production is the key to limiting the spread of bladder campion. Starvation through repeated tillage helps to control established weed patches.

Control Mechanisms

Tillage - Summerfallow - Intensive cultivation or mowing for two seasons is required to starve out bladder campion.

Preseeding tillage - Early spring germinating weed seedlings can be controlled with a shallow tillage prior to or at seeding.

Fall tillage - Deep cultivation with a discer will sever the weed roots below the crown leaving the plant in a weakened state for winter.

Rotation - Crop rotation will only suppress bladder campion, not eliminate it. Infested fields should not be put into perennial forage production, as this weed will proliferate if undisturbed. Cereals offer good competition and allow for postseeding tillage. Summerfallow is effective in controlling this weed, but mowing rather than tillage will lessen the risk of soil erosion. Annual crops cut for greenfeed allow for deep cultivation in spring and fall or can be cut before the main flush of weed seeds are set.

Seeding - Shallow tillage to destroy emerged shoots and seedlings should be done prior to or at seeding. Seeding of cereals should be deep (7.5 cm or 3 inches) if postseeding tillage is to be done. Seeding of other crops on infested land is not recommended if the weed is to be controlled.

Mowing - Repeated mowing of small patches of bladder campion in wastelands and perennial crops is laborious but effective.

CANADA THISTLE
Cirsium arvense (L.) Scop.

Life cycle - Perennial, reproducing mainly by horizontal roots, and seed.

Emergence - Shoots from horizontal roots appear on the soil surface near mid-April and continue to emerge throughout the summer. Seeds germinate from late May through to fall.

Flowering - Flowering begins in mid-June and continues into September.

Reproduction - Seed - Seed can be viable eight to ten days after flowering. Fresh seed will germinate readily or go dormant for up to three years. Although Canada thistle is a prolific seed producer, control should be aimed mainly at vegetative reproduction.

Vegetative - New roots, which develop from old, continually replace weak or dead roots. Horizontal growth is rapid and roots can regenerate from small pieces. The low point of food reserves in the roots is early to mid-June, when flowering begins. Control measures to starve roots should begin at this time.

Competition - Canada thistle is extremely competitive. Established perennial forages will compete well provided they are cut twice each year. The following table shows estimated yield losses of canola and caused by Canada thistle.

Estimated yield losses (%) caused by Canada thistle.

Canada thistle	%Yield Loss	
per square foot	Barley	Canola
0.5	18	5
1	25	16
2	35	30
3	43	41
4	50	50
5	56	58

(From: J. O'Donovan, 1987)

Management Strategy - Root starvation is the key to controlling Canada thistle. Controlling seed set is secondary.

Control Mechanisms

Tillage - Summerfallow - The principles of root starvation apply in controlling Canada thistle in summerfallow. Control measures must continue when the land is cropped.

Preseeding tillage - Tillage prior to or at seeding will cut emerging thistle shoots, setting them back slightly. Postseeding tillage - Control of Canada thistle is not feasible by this means.

Fall tillage - It is important to practice fall tillage since food reserves will otherwise increase in the fall. Tillage of annual crops should begin as soon as possible after harvest. If moisture conditions allow, tillage repeated until freeze-up should occur as shoots reach 10 cm (4 inches).

Rotation - Oilseeds and specialty crops generally do not compete well on land infested with Canada thistle. Fall rye and winter wheat offer fall competition and weaken late fall thistle infestations. Annual cereals can be used in rotation if they are planted early and if land is tilled in the fall, after their removal.

Seeding - Early seeding of cereals allows them to better compete with Canada thistle. Perennial crops, such as alfalfa and crested wheatgrass, should be seeded slightly heavy and in moist soils to encourage strong emergence.

Mowing - Mowing is effective on summerfallow and eliminates the risk of erosion caused by tillage operations. If done every three to four weeks from June through September, the weeds will become weakened. In perennial forages, cut twice or more each year; thistles will die out in time.

Biological Control - One insect has been established on Canada thistle at one site in Alberta, the weevil **Ceuthorhynchus litura.** The larvae of this insect bore in the stems of the thistle, weakening and sometimes killing them. However, the thistle plants seems to be well able to compensate for this damage. **Ceuthorhynchus** increases and spreads very slowly from its release point and does not seem very promising as a biological control agent.

A beetle, **Lema cyanella,** which feeds on the leaves of Canada thistle, has been approved for release in Canada. It has not yet been released in Alberta because of problems in rearing enough beetles for release, but further attempts will be made.

Two other species have been established in the past but seem to be poorly adapted to our climate and eventually died out: a leaf-feeding beetle **Altica carduorum,** and a gall fly **Urophora cardui.** Attempts may be made in the future to use these again. Other insects are also being studied for possible biological control of Canada thistle.

CHICKWEED
Stellaria media (L.) Vill.

Life cycle - An annual or winter annual, reproducing by seed and stems rooting at the nodes. The winter annual form occurs only in mild climates.

Emergence - Two main flushes of emergence occur, early spring and late fall. Sporadic emergence occurs through the summer.

Flowering - Flowering occurs four to five weeks after emergence. Flowers open only for one day.

Reproduction -Seed - Seeds of chickweed are highly viable as soon as they are shed. Buried seeds require light before germination can take place. Most seeds germinate within three years after being shed, but deeply buried seed can survive for up to 60 years.

Vegetative - Chickweed will root at the nodes of prostrate stems in moist, loose soil.

Competition - Chickweed is not a strong competitor in established crops and grows only in bare patches, but seedling crops can be smothered when chickweed forms a mat and covers them. Chickweed is a problem since it remains green and can wrap around moving parts of harvest equipment. If weather is cool and wet, chickweed will grow on swaths delaying drying time and making pick-up difficult.

Management Strategy - Preventing seed production and preventing re-establishment after cultivation are the main control strategies. Special attention must be given to preventing growth and seed production in late fall.

Control Mechanisms

Tillage - Summerfallow - Summerfallow encourages the growth of chickweed because of the lack of crop cover which provides competition. Tillage operations should be done immediately following the first emergence and continue with each subsequent flush. The tillage operation must bury the chickweed or it will easily re-establish itself by rooting at the nodes on the stems.

Preseeding tillage - Early shallow tillage encourages weed seed germination. When the seedlings emerge the land should be tilled again and then seeded. Seeding will be delayed by approximately 10 days and some surface moisture will be lost.

Postseeding tillage - Postseeding tillage is not effective in controlling chickweed since the chickweed plant is dragged, not buried, so that it easily re-roots from stem nodes.

Fall tillage - Fall tillage is important to control chickweed that would otherwise set seed or overwinter. The best control will result when weeds are buried, not allowing the plant to re-root.

Rotation - Strong stands of perennial crops are beneficial in suppressing chickweed. Annual crops, once established, can also effectively suppress this weed. Summerfallowing must be thorough in spring and late fall to keep chickweed growth in check.

Seeding - Seeding rates for chickweed infested land can be increased by up to 25 per cent to encourage crop competition. Seeding may be delayed while waiting for the early spring emergence of chickweed.

Mowing - Close mowing will help to reduce seed set of chickweed, however, many prostrate plants will escape cutting.

CLEAVERS
Galium aparine L.

Life cycle - Annual, reproducing by seed.

Emergence - The main flush of seedlings is in midspring with fewer seeds germinating throughout the summe

Flowering - Cleavers flowers from June through August with seeds being produced from August to freeze up.

Reproduction - Seed - Cleavers produces large quantities of seed. They are difficult to separate from canola seed as they are similar in shape and size. Cleavers seeds become dormat in dry soil and can remain viable for one to three years.

Competition - Cleavers can be very competitive as it clings to crop plants when moving towards light. The trailing plants can become tangled in moving parts of harvesting equipment . Seed quality suffers when canola seed is infested with cleavers seed. Established forages should compete well with cleavers.

Management Strategy - Preventing seed production, especially in canola fields, and sowing clean seed are critical in controlling cleavers.

Control Mechanisms

Tillage - Summerfallow - Cleavers seed populations can be reduced through summerfallow. Weed flushes should be tilled to shallow depths to prevent seed production. Plants can re-root in moist soils so tillage is most effective under warm dry conditions.

Preseeding tillage - An early shallow tillage encourages germination of cleavers seeds. A second tillage operation, immediately before or at seeding destroys these seedlings. Seeding may be delayed, however, if this is not possible sow the crop early so that it gains a competitive advantage over cleavers.

Postseeding tillage - If preseeding tillage is performed then postseeding tillage should not be necessary. Early seeded crops may not benefit from postseeding tillage because crop growth may be too advanced before weed emergence is complete.

Fall tillage - Fall tillage will encourage cleavers seeds to germinate and the seedlings will be killed by frost.

Rotation - Rotations including summerfallow, cereals, and annual and perennial forages should help minimize cleavers populations. Winter annual cereals are especially effective. Growing canola on cleavers - infested land is not recommended because of the difficulty of cleaning cleavers seed from the crop

Seeding - Spring seeding of land infested with cleavers should be either very early or delayed until after the weed seedlings emerge.

Mowing - Because of the prostrate growing habit of cleavers, mowing is not effective.

CORN SPURRY
Spergula arvensis L.

Life cycle - An annual spreading by seed.

Emergence - Main seedling emergence is in mid-spring with sporadic emergence throughout the summer.

Flowering - Flowers mainly in July and through to September.

Reproduction - Seed - Seeds are produced from late July through September. Seeds remain viable for more than three years. Clover and grass seed can contain impurities of corn spurry seed.

Competition - Corn spurry is an aggressive competitor. It grows mainly on light, acid soils. Growth is very rapid and can smother out emerging crops.

Management Strategy - Preventing seed production and encouraging germination of existing seeds are the major control strategies.

Control Mechanisms

Tillage - Summerfallow - Badly infested land should be summerfallowed starting with shallow fall cultivation to encourage germination. The next season each successive tillage should be deeper to bring seeds to the surface to germinate. This system of control will be effective provided there is moisture for seed germination.

Preseeding tillage - A shallow tillage pass should be made at or prior to seeding.

Postseeding tillage - Postemergent harrowing is effective in cereals if corn spurry emerges with the crop.

Fall tillage - Harrowing or shallow cultivating in the fall will induce seeds to germinate exposing the seedlings to frost.

Rotation - Corn spurry infested land should be summerfallowed before being seeded to a crop. This is especially important prior to seeding perennial forages since forage seedlings can not compete with corn spurry. Once established, forages compete well with corn spurry.

Seeding - Sowing clean seed, especially legumes and grasses, is fundamental in preventing spread of corn spurry. If cereals are to be harrowed after emergence, seedling should be deeper than normal, to minimize crop injury.

Mowing - Mowing will stunt corn spurry growth, but cut shoots will quickly re-grow.

COW COCKLE

Saponaria vaccaria L. (= Vaccaria pyramidata Medic.)

Life cycle - An annual, reproducing by seed. Cow cockle appears to be a problem only in the brown and dark brown soil zones.

Emergence - Main seedling emergence is in early spring.

Flowering - Occurs in late June and July.

Reproduction - Seed - Seed is produced in late July and August with the majority germinating the following year and the remainder germinating the second year. All plant parts are poisonous, especially the seeds.

Competition - Cow cockle does not compete with established perennials but it competes with annual crop stands.

Management Strategy - Preventing seed set is crucial in the control of cow cockle.

Control Mechanisms

Preseeding tillage - Summerfallow - Clean summerfallow is effective in controlling this weed, since the seeds are only viable for a few years. The first tillage operation should be made after the main flush of weeds. Preseeding tillage - Early, shallow tillage encourages cow cockle seeds to germinate. When the seedlings emerge, the land should be tilled and seeded. Seeding will be delayed by about 10 days and some surface moisture will be lost.

Postseeding tillage - If seeding is delayed then postseeding tillage should not be required. If necessary, postemergent harrowing can be done on cereals.

Fall tillage - Fall tillage will destroy existing cow cockle seedlings and mature plants that have escaped.

Rotation - Perennial forages, grown for three to four years will greatly reduce cow cockle populations. Summerfallow is also effective in controlling this weed. Annual crops should be seeded up to 25 per cent heavier to encourage a strong crop stand. Flax should not be planted on infested land.

Seeding - Delayed seeding allows for spring tillage to control the main flush of cow cockle. Annual crops may be seeded heavy to ensure strong stands.

Mowing - Mowing of weedy patches before seed set, limits cow cockle populations.

DANDELION

Taraxacum officinale Weber

Life cycle - A perennial, reproducing mainly by seed. New plants can develop from severed root pieces.

Emergence - Throughout the growing season.

Flowering - Dandelion flowers appear throughout the growing season, being most abundant in spring.

Reproduction - Seed - Seeds are viable and ready for dispersal within two weeks of flowering. Dandelion seeds can survive for more than three years in the soil.

Competition - Dandelions are mainly a problem in weak forage stands. Fertilizing or renovating the stand will help decrease dandelion populations. Dandelions do not compete well in healthy, strong perennial crop stands. Dandelions are not usually a problem in annual crops that undergo tillage.

Management Strategy - Preventing seed production is of key importance in controlling dandelions, but it is not practical. Dandelions grow in many noncrop situations and seed can travel great distances. Instead, perennial forages should be managed to prevent dandelions from becoming established.

Control Mechanisms

Tillage - Summerfallow - Summerfallow should not be necessary to control dandelions. Spring and/or fall tillage destroy the roots beneath the crowns.

Preseeding tillage - Deep tillage to 10 cm (4 inches) will sever established dandelion taproots and destroy seedlings. A heavy duty cultivator followed by a rod weeder is most successful.

Postseeding tillage - Tillage to control established plants after seeding is not effective. However, it is effective for control of dandelion seedlings in cereals. Should dandelion seedlings be a problem, tillage can be done prior to or after crop emergence.

Fall tillage - Deep tillage to 10 cm (4 inches) will sever established dandelion taproots and destroy seedlings. A heavy duty cultivator followed by a rod weeder generally works well.

Rotation - Weak forage stands should be fertilized and re-seeded. If this is not successful the stand should be worked and seeded to an annual crop. Healthy perennial forages in the rotation for three to five years will reduce dandelion seed quantities. Most annual crops will compete well, as long as the crop stand is heavy and vigorous.

Seeding - Seeding should proceed as normal with heavy (+*25%*) seeding rates being used for perennial crops. Cereals that require postseeding tillage should be seeded deeper and heavier than normal.

Mowing - Mowing is not an effective means of control for dandelions, owing to its low growing habit.

FIELD BINDWEED
Convolvulus arvensis L.

Life cycle - A perennial reproducing by seeds and root buds.

Emergence - Seeds of field bindweed germinate throughout the growing season, with the peak germination in late spring. Shoot growth begins when day temperatures are near 14°C and night temperatures are at least 2°C.

Flowering - Flowering begins in early July and continues until freeze-up.

Reproduction- Seed - Seed set is enhanced by dry, sunny, weather. Seeds have a hard seedcoat and can survive in the soil for 20 to 30 years. Seed may not be produced by plants in frequently cultivated soils.

Vegetative - Seedlings produce a taproot which quickly develops lateral roots. Rhizomes develop from root buds, and shoots then develop from rhizomes. Each piece of rhizome is capable of starting a new plant.

Competition - Field bindweed competes poorly for light but is capable of competing for soil moisture because of its extensive root system. This weed can cause severe yield reductions and once established can cause crop lodging and can also interfere with harvesting.

Fall rye, winter wheat, alfalfa and crested wheatgrass compete well with field bindweed.

Management Strategy - Special attention should be given to preventive control measures since this is such a persistent weed. Preventing seed production and root starvation are the main control strategies.

Control Mechanisms

Tillage - Summerfallow - A tillage operation every three to four weeks from June through September is the only nonchemical solution for controlling field bindweed. This would need to be done for two seasons. A combination of cultivation, crop rotation, and herbicides is recommended to control infestations of field bindweed.

Preseeding tillage - Tillage before seeding should be fairly deep (10 cm or 4 inches) to cut the roots and delay shoot growth so that the crop seedlings have a competitive advantage.

Postseeding tillage - Postseeding tillage is only effective in controlling field bindweed seedlings in cereal crops.

Fall tillage - Food reserves in field bindweed roots are at a peak in October. Cultivation at this time is risky because the root pieces have the greater chance of survival when stored food levels are high. If necessary, herbicides can be used at this time for suppression, weakening the plant to affect its winter survival.

Rotation - Rotations including competitive plants such as fall rye, winter wheat, alfalfa and crested wheatgrass should be considered. Forages should not be used for pasturing unless the weed infestation is a solid stand since grazing causes the weed to spread. Perennial crops should be reseeded or worked down when the stand becomes weak.

Seeding - Seeding should be done as usual unless postseeding tillage is anticipated for cereal crops.

Mowing - Seed set of field bindweed will be minimized if it is cut with perennial crops. Prostrate plants generally escape cutting.

FLIXWEED
Descurainia sophia (L.) Webb

Life cycle - Annual or winter annual reproducing by seed.

Emergence - Seedlings emerge mainly in the fall and early spring.

Flowering - Overwintered rosettes begin to flower near the end of May. Spring-emerging flixweed starts flowering in mid-June. Flowering of both growth forms continues through the summer.

Reproduction - Seed - Flixweed shatters easily and produces large quantities of seed. Seeds can survive in the soil for more than three years.

Competition - Overwintered rosettes are strong competitors because of their rapid growth in the spring and use of valuable spring moisture before fields can be worked. Spring-emerging flixweed seedlings do not compete as well, especially in heavy crop stands. Flixweed can be a severe problem in perennial forage crops grown for seed.

Management Strategy - The winter annual adaptation is the strongest survival mechanism of flixweed. Preventing seed set and controlling fall rosettes are crucial steps in preventing the spread of flixweed.

Control Mechanisms

Tillage - Summerfallow - Summerfallow alone will not control flixweed because seed remains viable in the soil for many years. Infested land need not be summerfallowed as long as spring and/or fall tillage operations are performed and effectively kill the weeds.

Preseeding tillage - Tillage before seeding is crucial in controlling flixweed. Regardless of the crop being seeded, a shallow tillage operation before crop seeding is necessary to destroy any existing seedlings or rosettes.

Postseeding tillage - Postseeding tillage should not be necessary if preseeding tillage is performed.

Fall tillage - Late fall tillage will control flixweed rosettes that would otherwise overwinter. Care should be taken to leave enough crop residues to protect the land against erosion.

Rotation - There is no nonchemical means of controlling flixweed in established winter annual crops. However, any heavy seeded, fertilized annual or perennial crop should compete well against flixweed.

Seeding - Crops should be seeded slightly heavy to encourage competition. Cereals anticipated to require harrowing after emergence should be seeded deeper than normal (7.5 cm or 3 inches).

Mowing - In the establishment year of perennial crops, mowing is effective in preventing flixweed seed set, although low growing plants may be missed.

GREEN FOXTAIL (Wild Millet)
Setaria viridis (L.) Beauv.

Life cycle - Annual reproducing by seed.

Emergence - The main seedling emergence occurs in late spring as soil temperatures increase, coinciding with crop emergence. Flushes occur over the summer especially following periods of high rainfall.

Flowering - Flowering of the main flush of weeds begins mid-July, with the later emerging green foxtail flowering through the summer.

Reproduction - Seed - The first green foxtail seeds mature two weeks after flowering begins. Dormancy lasts for 4-10 weeks, or longer if conditions are dry. Shallow buried green foxtail seeds remain viable in the soil for up to three years. Survival of seeds increases with depth of burial. Green foxtail plants are prolific seed producers. Seed production is reduced if plants are grown under heavy crop canopies.

Competition - Individual green foxtail plants are not strongly competitive. However, under certain conditions large populations can substantially reduce crop yields. Green foxtail is most competitive under high light and high temperature conditions. Early emerging green foxtail is generally more competitive than later emerging plants. High populations of this weed can be attributed to shallow early spring tillage, delayed seeding for wild oats control and broadcasting of fertilizers. Because green foxtail competes strongly for nitrogen, deep banding of nitrogen fertilizer will limit its availability. Barley and oats compete better with green foxtail than wheat does. However, green foxtail still represents the layout portion of dockage in all of these crops. Perennial forages compete well and should be grown for three or four years.

Management Strategy - Preventing seed set is the key to controlling green foxtail populations. Special efforts should be made to keep this weed from spreading to uninfested land.

Control Mechanisms

Tillage - Summerfallow - A season of summerfallow will greatly reduce populations of green foxtail. A deep first tillage operation will bring buried seeds to the surface to promote germination. Subsequent tillage operations should be shallow so that seeds remain near the surface for germination.

Preseeding tillage - Shallow tillage encourages seeds near the soil surface to germinate. For this reason, spring cultivation and seeding should be early so that the crop can gain a competitive advantage over later-emerging green foxtail.

Postseeding tillage - Postseeding tillage will probably be necessary in spring seeded cereals because soil disturbance at seeding encourages green foxtail emergence.

Fall tillage - In dry years, shallow fall tillage buries green foxtail seeds and encourages germination the following spring. In damp cool fall weather, green foxtail seeds should be left on the soil surface so that they can lose their dormancy and germinate. Green foxtail seedlings cannot survive the winter.

Rotation - Summerfallow reduces green foxtail numbers. Three to four years of perennial forage crops will also decrease green foxtail populations because the seeds are only viable for about three years. Badly infested crops should be cut for greenfeed before the green foxtail seeds shatter out. Cereals and oilseeds are the most difficult crops in which to reduce green foxtail populations. However, if these crops are seeded early and heavy, they should prevent further infestations of green foxtail.

Seeding - Seeding of perennial crops should take place after the main emergence of green foxtail, and subsequent shallow tillage. Cereals should be seeded as early as possible to increase competitiveness. If they cannot be seeded early they should be seeded deep and heavy so that postseeding tillage can be done. Seed oilseeds early and slightly heavy to encourage a competitive crop stand.

Mowing - Mowing of perennial forages is effective if it can be done before green foxtail goes to seed. However, seed set is usually in mid-June, before hay is ready to be cut.

HEMP NETTLE
Galeopsis tetrahit L.

Life cycle - Annual reproducing by seed.

Emergence - Hemp nettle emerges mainly in mid-spring with scattered emergence through the summer.

Flowering - Hemp nettle flowers from July through September

Reproduction - Seed - Seeds of hemp nettle are covered by a hard seed coat which prevents them from germinating for up to three years. Warm soil temperatures encourage seed germination. Large quantities of seed are produced by each plant starting in early August. Plants cut near maturity contain enough moisture and nutrients to ripen the seeds.

Competition - Hemp nettle is a vigorous competitor with crop plants for space and nitrogen. The weed often germinates at the same time as annual crops causing early competition.

Management Strategy - It is difficult to manipulate the germination of existing weed seeds; so instead, limiting seed production should be the control strategy.

Control Mechanisms

Tillage - Summerfallow - Firm and moist shallow-cultivated summerfallow provides conditions for dormant seeds to germinate. Once emerged the seedlings can be destroyed by cultivation.

Preseeding tillage - Combined tillage and seeding, after weed emergence, will destroy the majority of weed seedlings. The emerging crop then has the competitive advantage over the weeds.

Postseeding tillage - Postseeding tillage is risky and should be done only when other control measures are not feasible.

Fall tillage - Early fall tillage destroys hemp nettle plants and encourages germination of seeds in the soil.

Rotation - Badly infested land should be put into perennial forages for at least three years. The forage should be cut each year before weed seed set. Management to improve forage growth should inhibit hemp nettle. Annual crops will not compete well with hemp nettle. However, if cereals are used in the rotation then postseeding tillage can be done, if necessary. Summerfallow works well in the crop rotation. It allows for seeds to germinate and emerge to be destroyed by cultivation.

Seeding - Early spring seeding of annual crops, when possible, will allow the crop to emerge before hemp nettle. Seeding of cereal crops at regular times can be followed by postseeding tillage, if the cereals are seeded deep. If seeding is delayed, the seeding operation will destroy hemp nettle seedlings. An early maturing crop should then be planted. Perennial crops can be seeded after the main emergence of hemp nettle, sothat preseeding tillage destroys existing seedlings.

Mowing - Close mowing of perennial crops prior to weed seed set decreases hemp nettle populations.

KOCHIA

Kochia scoparia (L.) Schrad

Life cycle - An annual, reproducing by seeds.

Emergence - Most kochia seeds germinate before mid-May.

Flowering - Flowering takes place from July through September

Reproduction - Seed - Kochia can be a prolific seed producer, but its seed production is usually disrupted by cutting of perennial crops or harvesting of annual crops. Kochia seeds do not remain alive in the soil for more than a year.

Competition - Kochia is a strong competitor especially on dry, and/or saline cultivated land. It tolerates salinity levels too high to support most crop growth and has been found to reduce salinity levels of saline soils. Because of this, kochia can be considered to be beneficial. It also helps to stabilize the soil and it is palatable to livestock.

Management Strategy - Preventing seed production for a year eliminates kochia infestations.

Control Mechanisms

Tillage - Summerfallow - One year of summerfallow reduces kochia populations because no new seed is produced. The first tillage pass should be made in late May after kochia emergence.

Preseeding tillage - The seeding operation generally destroys most kochia seedlings.

Postseeding tillage - Postseeding tillage should not be necessary since most kochia seeds germinate prior to seeding and are destroyed at seeding.

Fall tillage - Fall tillage should not be required specifically for kochia unless plants are setting seed.

Rotation - Clean summerfallow is effective in limiting kochia spread. Infested land could be seeded to salt tolerant perennial forages which are mowed before kochia set seed. Strong annual crops should compete with kochia as long as the land is not too saline for the crop.

Seeding - Seeding may need to be delayed slightly until the main emergence flush of kochia is complete.

Mowing - If possible, cut perennials before kochia produces seed. Harvesting of annuals will usually disrupt kochia seed set.

LAMB'S-QUARTERS
Chenopodium album L.

Life cycle - An annual, reproducing by seeds.

Emergence - Lamb's-quarters emerges mainly in early spring with sporadic germination through the summer.

Flowering - June through September.

Reproduction - Seeds ripen from August through fall. Lamb's-quarter seeds live in the soil for up to 20 years. Dormant seeds are produced under long day lengths. Non dormant seeds are produced under short days. Dormancy can be broken by bringing the weed seeds to the soil surface. Crop seed often contains lamb's-quarters seed so all seed should be cleaned prior to use.

Competition - Lamb's-quarters competes with crops to some extent, but it is not very aggressive. This weed can rob the crop of valuable nutrients and moisture.

Management Strategy - Preventing seed production is the key to controlling lamb's-quarters.

Control Mechanisms

Tillage - Summerfallow - Badly infested land can be summerfallowed every three years to suppress lamb's-quarters populations.

Preseeding tillage - If moisture allows, use preseeding tillage to encourage germination by bringing seeds to the soil surface. Seeding may need to be delayed slightly so that the main weed flush has emerged.

Postseeding tillage - If preseeding tillage and delayed seeding are used, then postseeding tillage should not be necessary. However, if the weeds are a problem after cereal emergence, they can be destroyed by harrowing.

Fall tillage - Fall tillage encourages seedling emergence and destroys weeds that may otherwise set seed.

Rotation - Summerfallowing every three to four years will help to minimize lamb's-quarters infestations.

Perennial crops maintained for three or four years should reduce weed seed production. Heavy plant canopies reduce light levels and inhibit germination of lamb's-quarters seeds.

Annual crops that are used in a rotation to suppress lamb's-quarters should be seeded after the main flush of weeds has been destroyed. The crop then has a competitive advantage and the crop canopy will inhibit remaining lamb's-quarters germination.

Seeding - Clean seed of all crops before use since lamb's-quarters seed is a common impurity in forage and cereal seed.

Seeding of spring planted crops should be delayed until the majority of lamb's-quarters have emerged so that they can be destroyed at seeding.

Mowing - Lamb's-quarters cannot withstand cutting, so close mowing will eliminate the weed in perennial crops. Mowing of headlands will prevent seed production and spread of lamb's-quarters into fields.

NARROW-LEAVED HAWK'S-BEARD
Crepis tectorum L.

Life cycle - An annual or winter annual reproducing by seeds.

Emergence - Main flushes emerge from mid-May to mid-June and from early August to mid-September. The first flush develops as annuals and the second develops as winter annuals. Sporadic emergence occurs at other times.

Flowering - Winter annuals flower the year after emergence between mid-June and mid-July. The annual form flowers from early July through August.

Reproduction - Seed - Seeds of winter annuals are set from mid-July to mid-August. Seeds from annuals mature from early August through fall. Seeds exhibit little or no dormancy, losing their ability to germinate after about five years.

Competition - Narrow-leaved hawk's-beard is a serious weed of perennial forages. The winter annual form competes with established forages and the annual form competes with seedling forages and with special crops, cereals and oilseeds. The most serious infestations of this weed are in weak crop stands.

Management Strategy - Preventing seed set and encouraging strong crop stands are the main control strategies.

Control Mechanisms

Tillage - Summerfallow - Summerfallow is effective in reducing populations of narrow-leaved hawk's-beard. Plants can easily re-root after tillage, especially if conditions are wet. As a result tillage operations should be done during hot, dry weather. Tillage passes should be performed after the main flushes of emergence, and in the fall to destroy winter annual rosettes.

Preseeding tillage - Early, thorough spring tillage destroys weeds that may have overwintered. Annual crops can then be seeded. Perennial crops should not be seeded until after the first flush of seedlings have been destroyed by cultivation.

Fall tillage - Thorough cultivation should be done in the fall, after fall emergence is complete. This is usually around mid-September. If possible, conditions should be dry so that the rosettes do not re-root.

Rotation - Strong perennial crop stands should be kept for three to four years to discourage weed growth. If perennial crops become infested with narrow-leaved hawk's-beard the stand should be worked under and summerfallowed until the following year.

Annual crops in the rotation should be well fertilized and seeded heavy to encourage competition against the spring flush of weeds.

Summerfallow can be effective in controlling narrow-leaved hawk's-beard. Shallow tillage should be performed after spring and fall weed emergence as required during the season.

Seeding - Annual crops should be seeded heavy after the spring emergence flush has occurred. Perennial crops can be seeded after the spring emerged weeds have been destroyed by tillage. Fall seeded crops should be seeded after the fall flush of weed seedlings have been tilled.

Mowing - Mowing of narrow-leaved hawk's-beard in perennial crops should be done prior to seed production. This is especially important in establishment years of perennial crops.

NIGHT-FLOWERING CATCHFLY
Silene noctiflora L.

Life cycle - Annual or winter annual reproducing by seed.

Emergence - There is no definite period of germination but most emergence is from mid-April to mid-July. Sporadic germination occurs through to fall.

Flowering - Night-flowering catchfly flowers from mid-June through September. Mature seeds are produced about a month after the onset of flowering.

Reproduction - Seed - This weed is a heavy seed producer. The seed is highly viable. Immature seed from unopened capsules can germinate. The weed seed is easily spread with alsike clover as the seeds are the same shape and size. A short post-harvest dormancy may exist but seed can remain viable for more than three years in the soil.

Competition - Night-flowering catchfly, especially the winter annual form, is a strong competitor in moist areas. Established forages compete well and should remain for at least three years to deplete weed seed reserves in the soil.

Management Strategy - Controlling the winter annual form in the first season and sowing clean seed are the keys to controlling this weed.

Control Mechanisms

Tillage - Summerfallow - Reduce heavy populations of night-flowering catchfly by summerfallowing.

Preseeding tillage - It is difficult to know when to use tillage to control night-flowering catchfly seedlings because of the wide germination span. However, early spring tillage will kill any overwintered seedlings and the early germinating annuals.

Postseeding tillage - Do postseeding tillage cereals only when other control measures are not feasible.

Fall Tillage - Late fall tillage will control rosettes of the winter annual form that would otherwise overwinter.

Rotation - Rotations of at least three years in perennial forages will reduce seed numbers in the soil. Summerfallow will also help to deplete seed reserves.

Seeding - Spring tillage at or prior to seeding destroys weed seedlings and allows the crop to gain a competitive advantage over the weeds.

Mowing - Mow before seed set to control night-flowering catchfly, especially in the establishment year of forages.

QUACK GRASS
Agropyron repens (L.) Beauv.

Life cycle - A perennial spreading mainly by underground rhizomes and by seed.

Emergence - Seedling and shoot emergence begin in early spring. Rhizome growth is renewed each year from buds at the base, mainly near the end of the growing season. When rhizomes are cut from the parent plant, new shoots will form.

Flowering - Flowers generally appear from late July through to frost.

Reproduction - Seed - The amount of seed produced is highly variable. Buried seed can become dormant. Seed remains viable in the soil for up to four years. Seed is a contaminant of forage grass seed.

Vegetative - Each bud on the underground stems is capable of forming a new plant. Most buds remain dormant until the underground stems are cut into pieces. Once cut, the root piece sends up new shoots to the soil surface.

Competition - Quack grass is a strong competitor with crops for several reasons. Firstly, it can maintain high growth rates in cool weather. Second, quack grass can tie up a large percentage of N, P, and K from the soil making them unavailable to the crop. Thirdly, this weed reproduces very effectively from vegetative plant parts. Further, it is suspected that quack grass contains allelopathic toxins that inhibit growth of crops or other weeds. The allelopathic effect appears to be linked to dead plant parts. It is not clear whether the inhibitor is a product of microbial activity or if it is leached from the quack grass itself. Perennial crops encourage the shallow rooting of quack grass, so that roots can be destroyed more easily when the crop is worked under.

Management Strategy - Exhausting the root reserves is the main control strategy.

Control Mechanisms

Tillage - Summerfallow - Unlike other perennials quack grass does not have a weak phase in its life cycle, so there is no key time when tillage is more effective than another. Two common methods of cultural control are "dragging out" and shredding. These involve intensive tillage operations and may be combined with herbicides to reduce soil pulverization. Two seasons of control measures will likely be needed to reduce weed populations.

The principle behind the "shredding" is to cause the quack grass rootstocks to produce underground growth and at the same time prevent this growth from reaching the sunlight and producing leaves. Thus the buds on the rootstocks use their reserve food material trying to develop sufficient leaf area for the manufacture of food. The frequent shredding of the rootstocks stimulates a large number of dormant buds to grow, leading to the exhaustion of the food reserves. This can be accomplished with thorough tillage operations using a plow, rotovator, or one-way disc. Each operation should be carried out before the quack grass growth reaches 5 cm (2 in.) Infested patches should be tilled separately from the remainder of the field.

The principle behind the "dragging-out" method is to bring the intact rootstocks to the surface to dry out. This method is more effective under hot, windy, dry conditions. A cultivator with a cable weeder, rod weeder with oscillating harrows behind, "drags out" the rootstocks.

Half-way measures of cultural weed control may result in a better stand of quack grass. Follow-up tillage is required to prevent this weed from reinfesting a cleaned field. Sowing a competitive crop such as fall rye, barley, or canola will maintain crop yields in a quack grass infested field.

Preseeding tillage - Avoid tilling quack grass infested patches at this time if possible or new plants formed from underground stem pieces will be impossible to control in the crop.

Postseeding tillage - This method is not effective without damaging the crop.

Fall tillage - Repeat tillage from harvest to freeze-up to weaken quack grass stands. Do it before top growth reaches 5 cm (2 in.). In a wet fall, repeated mowing or grazing will create the same results as fall tillage. Fall applications of herbicides may be effective if good growing conditions exist.

Rotation - Quack grass is more likely to become established and multiply where land is cleared or broken than where it is left undisturbed. Perennial grass and legume mixes will not strongly compete with this weed. However, quack grass root systems will develop near the surface and become weak. Quack grass makes good hay and can be cut with the forage crop to weaken the quack grass stand. Hay should be cut before weed seed is produced.

Barley and fall rye will provide good annual crop competition.

Summerfallow allows a season of control to aim at eradicating quack grass.

Seeding - Seeding spring crops early to help the crop compete with quack grass.

Mowing - Repeated mowing can be an effective way of depleting root reserves of quack grass, if practical.

REDROOT PIGWEED
Amaranthus retroflexus L.

Life cycle - An annual reproducing by seed.

Emergence - Seeds require high soil temperatures to germinate. Seedlings emerge mainly in June and continue to emerge until fall if moisture conditions are adequate.

Flowering - Flowering is correlated with latitude, with northern populations flowering earliest. On average, flowering begins in early July and continues until mid-September.

Reproduction - Seed - Redroot pigweed is a heavy seed producer. Seeds will not germinate unless they are within two inches of the soil surface. Longevity of seeds appears to increase with depth of burial. Reports of longevity vary from 3 to 40 years. Seeds are commonly found in clover and grass seed, especially alsike and timothy.

Competition - Redroot pigweed is a strong competitor in root crops and potatoes but does not compete as effectively with crops with narrow row spacings, especially if they are seeded early. Since redroot pigweed does not emerge until June, early seeded crops get a head start and compete well.

Management Strategy - Preventing seed production is the key to controlling redroot pigweed.

Control Mechanisms

Tillage - Summerfallow - Redroot pigweed is prevalent on fallow land because it germinates after most weeds emerge. Give a shallow tillage within four weeks of weed emergence. Older plants often recover from cultivation.

Preseeding tillage - Do a shallow tillage to encourage redroot pigweed germination in the late fall.

Postseeding tillage - Cereals can be harrowed when in the one-to-four leaf stage when seedlings emerge.

Fall tillage - Late fall tillage encourages late spring germination of redroot pigweed seedlings. Older plants may recover from tillage and if nearing maturity can produce ripe seeds even after stems are severed.

Rotation - Use clean summerfallow and perennial forages seeded with weed-free seed in rotations to control redroot pigweed. Most annual crops, except potatoes and field root crops, also do well in the rotation.

Seeding - Early seeded crops have a competitive advantage over later emerging redroot pigweed.

Mowing - Mowing is not effective. Older plants are able to recover and quickly produce axillary flowers.

RUSSIAN THISTLE
Salsola pestifer A. Nels. = (S. kali L. var. tenufolia Tausch)

Life cycle - An annual, reproducing by seed.

Emergence - Seedlings emerge in early spring.

Flowering - Flowers appear from July until frost.

Reproduction - Seed - Seeds ripen from August through to frost and remain viable for up to three years. Plants break off at maturity and tumble across the land spreading seeds.

Competition - Russian thistle cannot compete well against growing crops, but after crops are harvested, the stunted seedlings begin vigorous growth.

In very dry years Russian thistle may be the only available feed as it thrives in dry conditions.

Management Strategy - Preventing seed production is the main strategy for control.

Control Mechanisms

Tillage - Summerfallow - Badly infested fields will benefit from summerfallow. Plants should be buried, if possible.

Preseeding tillage - A shallow, early tillage encourages weed seed germination. Seeding the crop destroys emerged seedlings.

Postseeding tillage - Harrow prior to emergence, or when the crop is in the one-to-four leaf stage, to destroy Russian thistle seedlings in cereals.

Fall tillage - Cultivate after crops are removed to destroy weeds that survive in the crop. This is extremely important since Russian thistle growth is vigorous after crop removal and can set seed until frost.

Rotation - Include summerfallow in the crop rotation if Russian thistle populations are high. Any strong crop stand does well in the rotation, as long as control measures are taken when the crop is removed.

Seeding - A shallow tillage plus seeding will destroy Russian thistle seedlings.

Mowing - Weeds larger than seedlings can be controlled by mowing if they become established in perennial crops or wastelands.

SCENTLESS CHAMOMILE
Matricaria maritima L.

Life cycle - An annual, biennial or shortlived perennial with an indeterminate growth habit, reproducing by seed.

Emergence - Annuals emerge in late spring after spring crop seeding. The biennial forms germinate in the summer or fall and overwinter as a vegetative rosette. Short lived perennials produce seed two years in succession, early in the season. The second year's growth is initiated from the previous year's root system.

Flowering - Scentless chamomile has an indeterminate flowering habit. This means that flowers and seed are continually formed. At any one time these plants can possess flowers, immature and mature seed. This growth habit makes eradication very difficult.

Annual scentless chamomile, in a competitive crop situation, will not usually flower until the crop is removed. In a noncompetitive situation, flowering of annuals begins in early July. Second year growth of biennial scentless chamomile, begins to flower in late May or early June. Short-lived perennial forms begin to flower in late May and continue through the summer.

Reproduction - Seed - Scentless chamomile is a prolific seed producer, a single plant can produce as many as one million seeds. Annuals set seed in late August or early September. Biennials set seed as early as mid-June, as do short-lived perennials. Seeds can live for up to 20 years in the soil. Shallow seeds will germinate more readily than deeply buried seeds.

Vegetative - Growth of the short-lived perennial form is initiated from the previous year's root system.

Competition - Because the annual form emerges late, the seedlings do not cause much competition when the land is in crop. After crop removal the annuals proliferate. Biennials and short-lived perennials vigorously compete, especially in their second year. Significant crop yield reductions can occur. Grass and clover seed can contain scentless chamomile seeds, the seedlings of which compete with the emerging crop and can become established in the crop stand. Early maturing canola competes well as it prevents light from reaching the scentless chamomile plants. A strong perennial grass stand will also compete well. Scentless chamomile adapts readily to new growing conditions so competition alone will not provide control.

Management Strategy - Preventing seed set and encouraging germination of existing seed are the two main control strategies.

Control Mechanisms

Tillage - Summerfallow - Repeat shallow tillage to encourage existing seeds to germinate and subsequently be destroyed. In heavy clay soils clumps around the weed roots are difficult to break up and weeds get re-established. To remedy this, use shallow cultivation followed one to two days later with harrowing to break clumps and expose roots.

Preseeding tillage - Spring cultivation destroys any overwintered scentless chamomile plants and spring-emerged seedlings. Cultivation should be followed in two days by harrowing to break up root balls. Planting a short season crop will allow time for additional spring tillage, if moisture allows.

Postseeding tillage - Harrow cereal after seeding to destroy later emerging weed seedlings. Postseeding tillage should not be a substitute for preseeding tillage.

Fall tillage - Cultivate after harvest to prevent weeds that have been suppressed by the crop from going to seed. Fall tillage also destroys biennials that would otherwise overwinter.

Rotation - Strong perennial grass stands help to bring the weed problem under control. Early maturing canola provides competition especially for annual scentless chamomile. Extremely weedy fields can be summerfallowed; remember that scentless chamomile proliferates when it has no competition.

Seeding - Till at seeding to destroy scentless chamomile seedlings. Increase seeding rates slightly to encourage a stronger crop stand for increased competition.

Mowing - Mowing for control of scentless chamomile is not effective. After cutting the weeds form new flowers and continue seed production.

SHEPHERD'S-PURSE
Capsella bursa-pastoris (L.) Medic

Life cycle - Summer and/or winter annual, reproducing by seed.

Emergence - Summer annuals emerge mainly in late spring, flowering and producing seed throughout the summer. Winter annual seedlings emerge in late summer and overwinter, continuing growth the following spring.

Flowering - Summer annuals flower from the end of June until fall. Winter annuals begin flowering, from the overwintered rosettes, in early spring and continue throughout the summer.

Reproduction - Seed - Seeds can germinate when mature or go dormant, remaining viable in the soil for up to 30 years.

Competition - Shepherd's-purse is a strong competitor in seedling crop stands, but will not compete with strong, established crops.

Management Strategy - Preventing seed production and controlling fall growth of winter annuals are the keys to controlling shepherd's-purse. As a winter annual, this weed can flower and set seed in early spring before fields can be worked, and before perennial forages require mowing.

Control Mechanisms

Tillage - Summerfallow - First working in spring destroys emerged seedlings and escaped winter annuals. Work in summer, when necessary, to control summer germinating seeds. Fall working controls the winter annual rosettes.

Preseeding tillage - Do shallow tillage in early spring if overwintered weeds are a problem. Seeding operations will destroy most spring emerged seedlings. Delay seeding until the main weed flush emerges, if possible.

Postseeding tillage - If tillage is done prior to or at seeding then postseeding tillage should not be required.

Fall tillage - Controls rosettes that would otherwise overwinter and stimulates annual weed seed germination. Do shallow tillage should be done in early October using an implement that will preserve crop residue.

Rotation - Crop rotation alone will not eliminate this weed since it can be a problem in all crops. Summerfallow will help reduce seed reserves in the soil. **Seeding** - Delay seeding until late spring when the main flush of summer annual seedlings has emerged. Shallow tillage at or prior to seeding will destroy the seedlings. Seed an early maturing crop immediately following tillage. Increase seeding rates, up to 25 per cent heavier than normal, to give the crop competitive advantage over shepherd's-purse, provided there is adequate moisture.

SMARTWEEDS - annual
Polygonum spp.

Life cycle - Annuals reproducing by seed.

Emergence - Seedlings emerge mainly in rich moist soils in early to midspring.

Flowering - Flowers inconspicuously from July to October.

Reproduction - Seed - Seeds mature from late July through to frost, and can remain viable for up to 50 years. Smartweed seeds are difficult to separate from flax seed and clover seed.

Competition - Strong stands of annual cereals and perennial forages will compete with annual smartweeds. Flax and most specialty crops will not compete. Smartweeds can delay harvest because they slow the drying of the swaths.

Management Strategy - Preventing seed set and encouraging germination of existing seed are the keys to controlling annual smartweeds. Drain low lying areas to destroy the habitats for smartweed.

Control Mechanisms

Tillage - Summerfallow - Annual smartweeds will be subdued by repeated tillage. However, soil seed reserves usually cause re-infestation the year after summerfallowing.

Preseeding tillage - As seedlings emerge from shallow depths, do a shallow preseeding tillage to encourage seed germination. The seedlings are destroyed during the seeding operation.

Postseeding tillage - Eliminate smartweeds that emerge after seeding cereals by harrowing. Do harrowing before the crop emerges or when it is in the one-to-four leaf stage, prior to tillering.

Fall tillage - Encourages germination of seed as the seed is brought to the surface with fall tillage.

Rotation - Perennial forage crops compete for moisture and discourage growth of smartweeds. Strong cereal stands do well in suppressing annual smartweed growth. Low lying areas can be seeded to grasses. Summerfallow will prevent seed production and decrease soil seed reserves.

Seeding - Heavy seeding of cereals increases their competitive ability. Tillage at seeding will eliminate existing weed seedlings.

Mowing - Frequent mowing of grass seeded low areas controls annual smartweeds until the grass is well established.

SMARTWEED - perennial
Polygonum spp.

Life cycle - Perennial, reproducing mainly by creeping rootstocks since viable seeds are seldom produced in our climate.

Emergence - New vegetative growth emerges in late May and early June. Seeds germinate in midspring.

Flowering - Flowers appear from late June to September.

Reproduction - Seed - Viable seeds are seldom produced in our climate.

Vegetative - On dry land, plants reproduce by sending up shoots from coarse, woody, underground stems. Plants growing in water reproduce from floating branches.

Competition - Perennial smartweeds are strong competitors with forages and field crops; once established they become the predominant species. Fall rye and barley are the best choices for a competitive crop. Control of established stands may require taking the land out of production.

Management Strategy - Preventing spread and starving the root system are the major control concerns. Controlling patches of these weeds is critical so that it does not become a field scale problem.

Control Mechanisms

Tillage - Tillage is ineffective in controlling perennial smartweeds and will only serve to spread them.

Summerfallow - Chemical fallow, mowing, or grazing are the only means of limiting perennial smartweed growth.

Preseeding tillage - Shoots emerge late so preseeding tillage is ineffective and may cause spread of the weed.

Postseeding tillage - Ineffective and may cause spread of the weed.

Fall tillage - Chemical application after crop removal may aid in weed suppression. Tillage is not effective.

Rotation - Chemical control may require that the land not be in production. Residues of herbicides, depending on what is used, may limit crops grown. Fall rye and barley offer the most competition in areas surrounding the weed patches.

Seeding - Avoid seeding infested areas since root disturbance will encourage weed spread.

Mowing - Mow or graze to eventually weaken the root system. This does not kill established weeds. This species tends to persist where the land is wet. Mowing may not be possible.

SOW-THISTLE - perennial
Sonchus arvensis L.

Life cycle - A deep rooted perennial reproducing from rootstocks and seeds.

Flowering - Flowers from June through August.

Reproduction - Seed - Seedlings emerge in late spring. Seed set is from July through September. Seed produced early in the season has a lower percentage germination than later maturing seed. Perennial sow-thistle seeds can germinate as they are dropped, or remain dormant for four years or more.

Vegetative - Perennial sow-thistle thrives in moist areas and reproduces from its tap roots and creeping rootstocks. New shoots are sent up in late spring. Old established infestations are more difficult to control than new ones.

Competition - Perennial sow-thistle competes strongly with crops. Fall infestations are weakened by seeding fall rye or winter wheat. Spring seeded oats or sweet-clover can be cut with the weed for silage. Forages, if cut twice per season, compete well. Straight grass stands, such as crested wheat grass, compete better than legume-grass mixtures. Use intensive tillage after harvesting annual crops.

Management Strategy - Preventing seed production and root starvation are the main control objectives.

Control Mechanisms

Tillage - Summerfallow - Repeat tillage or mowing, beginning when the weed is in the bud stage, to prevent seed production and promote root starvation. Begin tillage in early spring and continue through to fall to starve the root system. Drag roots on the soil surface where they are exposed to drying by sun and wind.

Preseeding tillage - Till to 7.5 cm (3 in.) prior to seeding to remove weed shoots. The crop can then emerge before the thistle regrowth.

Postseeding tillage - Harrow cereals to destroy perennial sow-thistle seedlings in late spring.

Fall tillage - Intensive tillage should follow crop removal. If land is susceptible to erosion the weeds should be controlled chemically or by mowing or grazing.

Rotation - Fall seeded crops weaken fall thistle infestations. Annual crops work in the rotation if weeds are controlled in the spring and fall. Perennial grasses compete better than legumes or legume-grass mixtures. A season of summerfallow dedicated to root starvation will give good control of perennial sow-thistle.

Seeding - Seeding into a freshly worked field gives the crop an advantage.

Mowing - Mowing will prevent restoration of food reserves if weed shoots are cut as they reappear. Perennial sow thistle leaves are unpalatable so are not likely to be consumed by livestock.

Biological control - An insect which attacks perennial sow-thistle has been established in Alberta. This is a gall-midge, **Cystiphora sonchi.** The adults are extremely small, delicate and short-lived, and are rarely seen. The damage to the plant takes the form of galls on the leaves, pimple-like swellings 3-4 mm in diameter in which the midge larvae live. Over 200 galls can occur on one leaf. The insect is well established and increasing in population at one release site in Alberta. Studies are being done to determine whether it causes significant damage to perennial sow-thistle. If this is confirmed, a supply of the insect will be available for redistribution. Another insect, a gall-fly which feeds in the flowers of perennial sow-thistle, has been tested but does not seem able to overwinter successfully under prairie conditions.

STINKWEED
Thlaspi arvense L.

Life cycle - Summer and/or winter annual reproducing by seed.

Emergence - Emergence of summer annuals occurs mainly in early spring. Winter annual seeds germinate in late summer and seedlings overwinter, continuing growth in the spring.

Flowering - Winter annuals can flower in early spring. Flowering and seed production of both forms takes place throughout the summer.

Reproduction - Seed - Stinkweed seed can live for up to six years in the tillage zone. Deeper buried seeds can live for up to 20 years, germinating when close to the surface. Dormancy of stinkweed seeds is encouraged by a thick seed coat.

Competition - Stinkweed can compete with crops for moisture and nutrients. However, a well fertilized crop that has a headstart over stinkweed, will compete well.

Management Strategy - Controlling fall rosettes of the winter annual form is important so that seed is not formed early the following spring. During any tillage operations plants with developed pods should not be turned under as they can continue to ripen on the stalks, under warm soil.

Control Mechanisms

Tillage - Summerfallow - First working should be done in early spring after emergence of stinkweed. Work shallow in summer, if needed. Fall tillage will control the winter annual rosettes.

Preseeding tillage - To minimize competition with the crop, spring germinated weed seedlings can be controlled with a shallow tillage operation prior to, or at, seeding. If overwintered stinkweed is a problem, an early spring tillage should be made.

Postseeding tillage - Postseeding tillage should not be required if preseeding tillage is done, or if seeding is after the main spring weed emergence.

Fall tillage - Controls rosettes that would otherwise overwinter and stimulates annual weed seed germination. Shallow tillage in early October with a field cultivator will conserve some crop residue while destroying existing weed seedlings.

Rotation - Crop rotation alone will not control stinkweed. A summerfallow year in the rotation will help to reduce seed levels in the soil, however, seedlings will still germinate from existing seeds.

Seeding - Seed after the main weed seedling emergence. Waiting for stinkweed emergence may delay seeding slightly.

Mowing - Mowing is effective in preventing stinkweed seed production but short plants may escape cutting.

STORK'S-BILL
Erodium cicutarium (L.) L'Her

Life cycle - Stork's-bill is reported to act as an annual, biennial or winter annual. In cultivated land in Alberta this weed seems to grow mainly as an annual.

Emergence - Main emergence in mid-spring and continuing through the summer.

Flowering - Flowers from early July through August.

Reproduction - Seed - Seeds readily germinate after tillage operations. Seeds remain viable for one to three years in the soil. Cleaning stork's-bill seed from small seeded crops can be difficult.

Competition - Soil disturbance during seeding encourages a flush of stork's-bill seedlings to emerge. These weeds emerge with the crop and compete strongly. Stork's-bill grows very dense and can withstand drought. It can cause severe yield reductions in dry years because it takes moisture from the crop. Heavily seeded, vigorous crop stands that have a head start over stork's-bill compete well. Fall rye provides good competition in light soils.

Management Strategy - Preventing seed production is the key to keeping stork's-bill under control.

Control Mechanisms

Tillage - Summerfallow - Stork's-bill is persistent on summerfallow because new flushes occur after each tillage. Each flush of weeds must be controlled before seed set. Repeated shallow tillage controls existing weeds and stimulates new weed growth, eventually exhausting the soil seed reserves.

Preseeding tillage - Early, shallow cultivation encourages germination of stork's-bill seeds. These seedlings can be destroyed with a second spring tillage at or before seeding the crop. Seeding date of the crop may be delayed slightly.

Postseeding tillage - Post emergent harrowing may give some stork's-bill control in deep seeded cereal crops. Fall tillage - Late fall tillage controls the biennial or winter annual rosettes which would otherwise overwinter and flower the following year.

Rotation - Stork's-bill is very competitive so infested fields should be summerfallowed or seeded to a competitive crop. Fall rye is a good crop choice. Stork's-bill seed production is prevented by the early harvesting of fall rye.

Seeding - Spring seeding of crops may be delayed if two tillage passes are required to kill emerging stork's-bill. If the need for postseeding tillage is anticipated, then a cereal crop should be planted. Seeding of winter annual crops should be done after fall emergence of winter annual stork's-bill.

Mowing - Mowing is only partially effective in controlling seed set of stork's-bill. This low growing weed will likely be missed by the mower.

TARTARY BUCKWHEAT
Fagopyrum tataricum (L.) J. Gaertn

Life cycle - Annual, reproducing by seed.

Emergence - The main seedling emergence is in early to mid-spring with sporadic germination throughout the summer.

Flowering - Flowering begins four to five weeks after plant emergence and continues until fall. Tartary buckwheat has an indeterminate growth habit so flowers, immature seed and mature seed can be found on a single plant at the same time.

Reproduction - Seed - Seeds of tartary buckwheat ripen three to four weeks after flowering. Mature seeds germinate after four to five weeks in warm, dry conditions or go dormant in cool, moist conditions. Seeds remain viable for up to three years. Dormancy lasts for the same amount of time. Seeds of wild and tartary buckwheat are the most common impurities of cereals and they account for a large percentage of dockage.

Competition - Tartary buckwheat is a strong competitor and is responsible for dockage in cereal grains. Its seed is similar in shape and size to cereals, so cleaning is difficult. The following table shows estimated yield losses of barley and wheat caused by various populations of tartary buckwheat.

Estimated yield losses (%) due to tartary buckwheat.

Tartary Buckwheat per square foot	% Yield Loss Barley	% Yield Loss Wheat
0.5	7	12
1	10	15
2	14	19
3	16	22
5	21	27
8	26	33
10	29	37
15	36	44
20	41	50

(From: J. O'Donovan, 1987)

Management Strategy - Eradication of tartary buckwheat seedlings and sowing clean seed are the strategies for controlling this weed.

Control Mechanisms

Tillage - Summerfallow - Because of the short dormancy period and viability of tartary buckwheat seeds, summerfallow can be effective in controlling this weed. Tillage operations encourage germination of wild buckwheat seeds, and subsequent tillage operations destroy the seedlings.

Preseeding tillage - Early, shallow tillage encourages germination. When the seedlings emerge the land should be tilled and seeded. Seeding will be delayed by about 10 days and some surface moisture will be lost.

Postseeding tillage - Postseeding tillage should be done in cereals only, when other control measures are not feasible.

Fall tillage - If warm, dry weather follows harvest then shallow fall tillage will encourage germination of tartary buckwheat seeds; the resulting growth is winter-killed. If conditions after harvest are cold and wet, the weed seeds will not after-ripen properly and tillage should be left until spring so that dormant seeds are not buried.

Rotation - Summerfallow and forage crops will help to reduce tartary buckwheat populations.

Seeding - Spring seeding should be delayed by about 10 days to allow emerged weed seedlings to be destroyed by tillage. Seeding at other times should be preceded by tillage if tartary buckwheat is a problem.

Mowing - Mowing delays shoot growth of tartary buckwheat but seed production resumes because of the plant's indeterminate growing habit. In forages, two cuttings per season are necessary to reduce tartary buckwheat populations.

TOADFLAX

Linaria vulgaris Mill.

Life cycle - Perennial, spreading by seed and by creeping roots.

Emergence - New shoots and seedlings emerge throughout the season, beginning in midspring. Seeds germinate from very shallow depths and will germinate on the soil surface.

Flowering - Flowers from June through fall, with shoots flowering earlier than seedlings.

Reproduction - Seed - Toadflax seeds have no dormancy period and can germinate as soon as they are shed. They remain viable for up to three years in the soil.

Vegetative - New shoots emerge from deep, running rootstocks. The roots serve to store food for the weed.

Competition - Toadflax is a strong competitor. Perennial and annual grasses offer the most competition against this weed.

Management Strategy - Prevention of seed production and root starvation are the key to control.

Control Mechanisms

Tillage - Summerfallow - The principal of root starvation should be applied here. Cultivation every three to four weeks, beginning in June, will bring toadflax under control but not eliminate it. Where wind erosion is a serious problem the land should be worked in alternate 80 m (87 yd.) wide strips of crop and fallow. These strips can be alternated the following year.

Preseeding tillage - Tillage prior to seeding will remove top-growth and give the emerging crop seedlings a better chance for establishment.

Postseeding tillage - Not effective for estabished toadflax control but can destroy existing weed seedlings in cereals. Tillage must be very shallow so that toadflax roots are not spread. Tillage will encourage a flush of weed seedlings as seeds are brought to the surface.

Fall tillage - Tillage should begin as soon as the crop is harvested. Regrowth between tillage operations should not remain above ground for more than five to eight days. This means that tillage will be necessary every three to four weeks until top growth is killed by frost.

Rotation - Alternate fallow and cropping will reduce toadflax stands in cereals, preventing interference with grain production. Three cycles of this rotation can reduce toadflax stands by 90 per cent. Fall rye is a good cereal choice. Two grain crops can follow a year of intensive cultivation without dramatic increases in the toadflax stand. Postharvest and preseeding tillage must be carried out in this rotation. Seeding to a perennial grass can follow a year of intensive summerfallow. Brome grass or crested wheat grass will compete well against toadflax.

Seeding - Cereals should be seeded heavily to compete well with toadflax stands.

Mowing - Mowing helps to decrease seed production but it will not eliminate toadflax stands.

Biological control - Two insects are already widely established on most toadflax infestations in Alberta, a small beetle **Brachypterolus pulicarius** and a weevil **Gymnaetron antirrhini.** These feed in the flowers; **Brachypterolus** usually appears earlier in the year and damages the tips of the flowering shoots, preventing many flowers from developing. These two insects can reduce the seed production of toadflax considerably. Toadflax infestations can be checked to see whether these insects are present on the flowers. **Brachypterolus** is a small, black, shiny, flat beetle about 2-3 mm in length. **Gymnaetron** is usually less abundant; it is slightly larger, rounder, duller and dark grey. If these insects are not present they can be introduced by placing infested toadflax branches among the flowering shoots of toadflax. Care should be taken not to spread toadflax seed around while transporting the insects.

Another insect is being tested in Alberta, the moth **Calophasia lunula.** The caterpillars of this moth feed on the leaves and flowers of toadflax. They are quite striking in appearance; the caterpillars are mottled with yellow, black and grey and up to 3 cm in length when full grown. This insect has been established in Ontario since 1962 and is sometimes abundant enough to completely defoliate small patches of toadflax. The initial releases have shown that the insect is able to breed and overwinter in Alberta, and releases will continue in 1987.

For identification of these insects, or to inquire where to obtain them, contact the Alberta Environmental Centre or Alberta Agriculture.

WHITE COCKLE

Silene alba (Mill.) E.H.L. Krause (= **Lychnis alba** Mill.)

Life cycle - A fleshy rooted biennial or short-lived perennial sometimes behaving as an annual. Reproduces mainly by seed or from buds on crown-root segments.

Emergence - Seed germination occurs from early spring through fall.

Flowering - Flowers from June to October with the earliest flowering being those plants that have overwintered.

Reproduction - Seed - White cockle is a prolific seed producer. Seed matures, in capsules, four to five weeks after flowering. Immature seeds can be viable only two to three weeks after pollination. Seed is viable for one to three years and a short dormancy may occur. White cockle seed requires light for germination, so tillage will encourage germination.

Vegetative - Reproduction from crown-root segments, with as little as 1 cm of root attached, is possible. Tillage operations should be done during dry weather so that these segments are not permitted to re-root.

Competition - White cockle can be competitive in the year of forage establishment but after cutting the competitive effects are less severe. Strong annual crop stands offer competition against white cockle.

Management Strategy - Preventing seed production and planting weed free seed are the most important concerns in controlling this weed.

Control Mechanisms

Tillage - Summerfallow - Plants will be destroyed with deep cultivation during dry weather. Soil seed reserves will decrease if plants are prevented from producing seed.

Preseeding tillage - Early spring tillage destroys overwintered plants and encourages germination of seeds by exposing them to light. A second spring tillage at seeding destroys any emerged seedlings.

Postseeding tillage - Since shallow tillage encourages the germination of white cockle seeds, postseeding tillage is not recommended.

Fall tillage - Carbohydrates are stored most rapidly in September and early October. Cultivation should follow this period and be deep enough to cut below the crowns of the white cockle plants. Care must be taken to clean cut the roots because new plants can form from root pieces.

Rotation - Rotations should include only summerfallow or annual crops if infestations are severe. Perennial forage seed often contains white cockle seed and the undisturbed perennial stand encourages white cockle to persist.

Seeding - A tillage operation before seeding will help to decrease white cockle populations by encouraging weed seed germination; tillage at seeding destroys the emerged seedlings.

Mowing - Mowing during flowering weakens the plants and prevents seed set. Secondary growth may emerge from crown buds in response to mowing.

WILD BUCKWHEAT
Polygonum convolvulus L.

Life cycle - Annual, reproducing by seed.

Emergence - The main seedling emergence is in midspring in association with the first prolonged warm period. Sporadic seed germination occurs throughout the growing season. Germination takes place in the top 5 cm (2 in.) of soil.

Flowering - Wild buckwheat has an indeterminate flowering habit so flowers, immature seed, and mature seed can be found on a single plant at the same time. Flowering occurs from May through October.

Reproduction - Seed - Seeds of wild buckwheat do not appear to live longer than three years. After maturing, the seeds can germinate in four to five weeks if weather conditions are warm and dry. If conditions are cool and wet, seeds will go dormant. Dormancy can last for up to three years. Seeds of wild and tartary buckwheat are the most common impurities of cereals and they account for a large percentage of dockage. Wild buckwheat seeds make good feed for poultry.

Competition - Wild buckwheat competes by entangling crop plants while growing towards the light. This weed can cause lodging in crops and become entangled in tillage and particularly harvest machinery.

Management Strategy - Sowing seed free of wild buckwheat and eradication of seedlings are critical in the management of this weed.

Control Mechanisms

Tillage - Summerfallow - Because of the short dormancy and viability of wild buckwheat seeds, summerfallow can be effective in controlling this weed. Tillage operations encourage germination of wild buckwheat seeds, and subsequent tillage operations destroy the seedlings.

Preseeding tillage - Early, shallow tillage encourages germination. When the seedlings emerge the land should be tilled and seeded. Seeding will be delayed by as much as 10 days and some surface moisture will be lost.

Postseeding tillage - Post-seeding tillage should be used in cereals only, when other control measures are not feasible.

Fall tillage - If warm dry weather follows harvest, then shallow fall tillage will encourage germination of wild buckwheat seeds; the resulting growth is winter-killed. If conditions after harvest are cold and wet, the weed seeds will not after-ripen properly and tillage should be left until spring so that dormant seeds are not buried.

Rotation - Summerfallow and forage crops will help to reduce wild buckwheat populations.

Seeding - Spring seeding should be delayed by about 10 days to allow emerged weed seedlings to be destroyed by tillage. Seeding at other times should be preceded by tillage if wild buckwheat is a problem.

Mowing - Mowing inhibits wild buckwheat growth but seed production resumes because of the plant's indeterminate growing habit. In forages, two cuttings per season are necessary to reduce wild buckwheat populations.

WILD MUSTARD
Sinapis arvensis L. (= Brassica kaber (DC.)

Life cycle - Annual, reproducing by seed.

Emergence - Main seedling emergence is in early spring with sporadic germination throughout the summer.

Flowering - Flowering of wild mustard takes place from May through fall.

Reproduction - Seed - Seed matures six weeks after full flower and can germinate as soon as it falls to the ground. Seeds that are buried immediately go dormant. Dormancy is a result of low oxygen levels beneath the soil surface. Seeds can remain viable for up to 60 years in the soil.

Competition - In early spring wild mustard has a competitive advantage over crops because of its rapid early growth. However, this weed requires high light intensity to grow well so it will not compete with heavily seeded, well fertilized crops.

Management Strategy - Seeds of wild mustard are viable for up to 60 years and are easily spread with canola seed. For these reasons, sowing clean seed and preventing weed seed formation are extremely important in the control of wild mustard.

Control Mechanisms

Tillage - Summerfallow - Wild mustard seedlings are easily killed with cultivation. The first tillage should be in mid to late spring when the main flush of weeds has emerged. Additional working should follow only when required.

Preseeding tillage - Shallow tillage at or before seeding will destroy existing weed seedlings.

Postseeding tillage - If weed seedlings are controlled at or before seeding then postseeding tillage should not be required.

Fall tillage - Fall tillage is required only if late germinating weeds will produce mature seed before freeze-up.

Rotation - Wild mustard is not eliminated through crop rotation because existing seeds remain viable in the soil for up to 60 years. Perennial forage crops discourage germination of wild mustard seeds. The seeds remain dormant when oxygen is not available.

Seeding - Seeding should occur as early as the land can be worked. This allows the crop to be competitive with the early emerging wild mustard.

Mowing - Mowing keeps wild mustard from going to seed. Fall mowing destroys maturing weeds if fall tillage is not possible.

WILD OATS
Avena fatua L.

Life cycle - An annual, reproducing by seed.

Emergence - The main flush of wild oat germination emerges in early to midspring. Seeds emerge from shallow depths if the soil is moist and from greater depths if dry. Cool, moist conditions promote maximum emergence so early seeded crops are usually the most heavily infested. Fall or early spring applications of nitrogen fertilizer have been shown to stimulate germination of wild oats. Growth of wild oat roots and shoots is slow for the first two weeks but it increases quickly thereafter. Most wild oat tillering occurs within a month of emergence. Sporadic germination of wild oat seeds can occur through the summer.

Flowering - Wild oats usually start flowering in early July from the tip of the panicle to the base. Seeds shatter as they mature and are shed by mid-August generally before the crop is harvested.

Reproduction - Seed - Mature seeds of wild oats are usually dormant when they are shattered. This dormancy is broken by an after-ripening period of warm, dry conditions. If moisture is available when dormancy is broken, the seeds will germinate. Otherwise they become dormant again. The after-ripening period is delayed if fall weather is cool and moist. Wild oat seeds contaminate most grains; they increase dockage and lower grades. Cleaning grain to remove weed seeds can be costly.

Competition - Many factors contribute to the degree of competition by wild oats. Competition is greatly influenced by the relative emergence dates of wild oats and the crop. When wild oats emerge before the crop, yield losses are greater than when the crop emerges first. Density and rates of growth of the weed and crop also influence competition. Increased growth rate and densities of wild oats increase crop yield losses. The following table shows estimated yield losses caused by various densities of wild oats in four crops. The yield losses must be adjusted according to the relative emergence dates of the crop and the weeds.

Estimated yield losses (%) due to wild oats. (The actual losses may vary from year to year depending on climatic conditions).

Wild oats per square foot	% Yield Loss Wild oats and crop emerged at same time				Time of emergence* factor (+/-)
	Barley	Wheat	Canola	Flax	
0.5	5	8	7	14	0.5
1	8	11	10	20	1
2	11	16	15	28	1
3	13	19	18	34	2
5	17	25	24	44	2
8	21	32	30	56	2.5
10	24	35	33	62	2.5
15	29	43	41	75	3
20	34	50	47	88	3

* The time of emergence information was developed experimentally for barley and wheat only. However, it may also be accurate for canola and flax. Add or subtract the appropriate number for every day wild oats emerge before or after the crop. For example, if wild oats at 2 plants per square foot emerge 3 days before barley, the yield loss changes from 11 to 14%.

(From: J.O'Donovan, 1987).

Wild oats may have allelopathic effects on other plant species. Straw of wild oats contains compounds that can inhibit germination and seedling growth of other plant species. The extent of this allelopathy has not been researched fully.

Management Strategy - Preventing seed set and encouraging germination of existing seed reserves are the objectives in controlling wild oats.

Control Mechanisms

Tillage - Summerfallow - It is difficult to prevent seed set of wild oats in annual crops unless the crop is taken off early for greenfeed or silage. Because of this a combination of summerfallow, chemical, and cultural controls should be used when attacking the wild oat problem. Summerfallowing increases the number of seeds that break dormancy so a new stand of wild oats will emerge after each tillage operation. Summerfallow can be grazed to control wild oats. Fall-seeded crops can be put in the same year as the fallow to offer competition against spring germinating wild oats.

Preseeding tillage - Tillage prior to seeding should be done before weeds reach the three leaf stage. This minimizes the moisture and nutrients they use. Tillage should be done in warm, dry weather so that the weeds cannot get re-established.

Shallow tillage in early spring promotes wild oat seed germination to a lesser extent than will fall tillage.

Postseeding tillage - Tillage at this time is important because weeds emerging prior to the crop are more competitive than those emerging with/or after the crop. Shallow cultivation of cereals with a rod-weeder or harrows eliminates late emerging wild oat seedlings. Tillage should be done prior to crop emergence.

Fall tillage - Fall tillage is useful if seeds have been exposed to two or three weeks of warm, dry weather. Shallow tillage will lightly cover wild oat seeds, promoting germination. A cultivator encourages more germination than does a discer or harrow. If fall weather is cool and moist, tillage should be avoided so that dormant wild oat seeds remain on the surface exposed to the elements.

Rotation - Fall seeded crops emerge early the next spring and smother the emerging wild oats. Fall seeded rye is generally more vigorous and competitive than winter wheat.
Seeding heavily infested land down to a perennial forage and leaving it for three or more years provides good wild oat control. However, some seeds can survive under sod and still reinfest the field when the sod is broken up.

Seed greenfeed crops such as oats, to combat a heavy infestation of wild oats. Seed early to enable a competitive advantage over the wild oats. Cut the crop before the panicles of wild oats start to emerge from the sheath to prevent seed production. Silage effectively destroys any seeds produced.

Use annual crops in the rotation, especially the more competitive crops so that yield losses are minimized and the wild oats are suppressed. Barley, canola and wheat are the most competitive small grains, in descending order. Annual crops that are poor competitors may require wild oat control by herbicides. Drill in phosphorous fertilizers with the seed to encourage crop growth and increase competition against the weed.

Summerfallow alone will not control wild oats, but it will help to deplete seed reserves and prevent new seed populations.

Seeding - Delay seeding to allow time for wild oat seedlings to be destroyed by tillage prior to or at seeding. Follow with a seeding of an early maturing barley variety. Yields may be reduced if seeding is delayed by more than 10 to 14 days.

Mowing - Mow wild oats before the panicles emerge as a preventative measure when an infestation is heavy and the crop is of low density. Observe regrowth to ensure wild oats do not go to seed.

INSECT CONTROL

Index

General

BIOLOGY

A thorough understanding of how insects live will result in sound, more economical pest control decisions. Although insect biology is a large subject a few words on this matter now will help you to anticipate insect problems.

Insect development can be classified as either complete or gradual (incomplete). Complete development proceeds through a series of distinctly different growth forms. Gradual development proceeds through a number of growth stages in which the young look very similar to the adult. Of these two groups, insects with complete development have biological traits that make them the more numerous group of pest species.

Insects with complete development hatch from the egg stage into the feeding and growing larval stage. Upon completion of growth, the larva changes to a nonfeeding, resting stage called the pupa (frequently called cocoon). During the pupal stage the insect is transformed into the adult. The adult is the reproductive and normally mobile stage of the insect's life cycle. This group of insects includes many species commonly found in crops, such as the beetles, the flies, the moths and butterflies, and others. Most often it is the larvae of these insects that damage crops. The larval stages are known by various common names such as caterpillar, maggot and grub.

Insects with gradual development also arise from eggs, but unlike insects with complete development, these insects go through a series of growth stages called nymphs before becoming adults. Nymphs and adults look very similar, except that the adults are larger and normally have wings. There is no resting stage (pupa) in this group; when the mature nymph sheds its skin for the last time, it becomes the reproductive adult.

Larvae of insects having complete development often consume foods different from those the adults consume. Thus, although cutworms are foliage or stem feeders, the moths consume only flower nectar. Many adult flies eat only nectar and pollen while the maggots may be predators (for example, aphid-eating larvae of syrphid flies), or saprophages (for example, maggots of fruit flies in rotting fruit) or plant eaters (for example, root maggots in canola).

Nymphs of insects with gradual development generally feed on the same food as the adult forms (for example, grasshoppers, aphids and thrips).

Information on where insects are to be found at different times of the year is helpful when trying to anticipate a pest problem. By uncovering grasshopper eggs laid along roadsides or other favored spots, cereal farmers can judge the potential abundance of these insects prior to planting. Since each pest's biology is different, producers should consult a handbook to become familiar with the appearance of both adults and the immature and their whereabouts.

ASSESS THE POTENTIAL FOR INSECT DAMAGE

Know your pest - Insect control may be necessary in one circumstance and not in another, depending upon the impact of natural insect mortality factors such as weather, crop condition, and natural enemies. You need to know the insect's biology - its habits, food needs, food preferences, reproductive cycle and habitat requirements. Then you must estimate under what circumstances populations will remain below economic levels/and how many insects it will take to cause economic damage. A large number of moths does not necessarily mean there will be a large number of caterpillars. Insects require certain conditions to multiply or to cause damage. A good food source for the larvae and good weather conditions are always necessary. Survival of each life stage (egg, larva, pupa and adult) will be influenced by weather, diseases, predators, food supply and many other factors.

Know your allies - You may find predators and parasites of pests during field scouting. You may also see dead or diseased insects infected with viruses, fungi or other pathogens. These are signs of natural pest control. If you know the enemies of your pest, you can judge whether they will contribute significantly to the mortality of the pest. You may also be able to avoid harming beneficial insects while controlling pests.

Know the economic threshold - An important concept of Integrated Pest Management is the economic threshold. This is the pest density at which control measures should be initiated to prevent an increasing pest population from inflicting economic injury. This density may be the number of pests per plant, pests per square metre, pests per sweep of an insect net, or some other suitable measure. The percentage of plants damaged is sometimes used in situations where pests develop inside plants, where pests are difficult to see or sweep because of dense or tough foliage, or as an additional piece of information to complement pest density. Several sampling methods may be required to monitor pest numbers because no single method is suitable for all species nor for the whole growing season. (The section, Field scouting, gives specific information.)

When pest density or damage reaches the economic threshold, a control measure should be applied. Using this specific event to time control eliminates unnecessary measures which increase costs of crop production, interfere with natural control of the pest, and may add to environmental pollution.

Know the economic injury level - A related concept, which determines the economic threshold, is the economic injury level (EIL). EIL is the lowest pest density causing damage equal to the cost of control measures. Several factors determine the EIL: crop response to injury, consumer demand for unblemished produce, crop market value, control costs, and the type of pest damage. Some of these factors are relatively simple to estimate; others are difficult because they depend on complex biological processes about which little is known. The factors are interdependent, to a degree, which causes the EIL to vary.

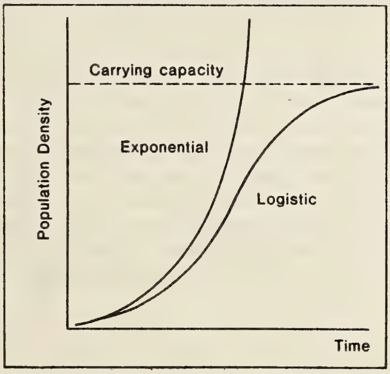
An important principle of IPM is that the presence of a pest in a crop does not mean economic damage will follow. Plants are able to compensate for injury caused by small numbers of pests and in some cases yields may even be increased. Because plants compete with each other for light, moisture and nutrition, the loss of some plants to insects can result in neighboring plants producing more. In such cases, small numbers of insects will not cause a reduction in overall yield. Insects may also have a pruning effect upon plants by suppressing the growth of one organ and increasing the weight of others. Small infestations of the bean aphid decrease tip growth of the bean plant and increase yields. No damage occurs when small numbers of a pest attack leaves or roots, which provide more nutrients than the harvestable parts of the plant can use. Flea beetles can destroy up to 50 per cent of the leaf area of canola seedlings without affecting yield.

Know the population dynamics of pest insects

The population dynamics of most pest insects follow a cycle of excessive abundance (outbreak) and relative scarcity. Outbreaks don't last forever in fact, outbreaks themselves cause the eventual reduction in pest numbers. Some pest insects, however, may not show a cycling in abundance: flea beetles in Manitoba have been abundant since the early 1970s and show no signs of significant changes in numbers.

An insect's habitat can maintain (carry) only a specific number of insects. The concept of carrying capacity is based on the principle that reproduction and survival change as numbers of insects per unit area (density) change. Without the limits of carrying capacity, insect numbers would increase exponentially. The exponential curve in the figure below shows how population density would increase. Producers will be familiar with the concept of carrying capacity as it applies to pasture and cattle.

Exponential population growth occurs in the absense of limitations.



At low population levels, species reproduce as though resources were unlimited. Many offspring are produced and mortality is low. At high population levels, fewer resources are available leading to a higher death rate, especially in the young. Fewer eggs are laid because of competition for available egg laying sites and food. Populations cease to increase when the insect population reaches the habitat's carrying capacity. Population growth restrained by the habitat's carrying capacity is shown in by the S-shaped logistic curve. Growth starts slowly, increases rapidly, and then stabilizes near the carrying capacity, providing no catastrophes, such as excess rain or extreme temperatures, occur.

In the real world, factors like food, breeding sites, space, time, weather, parasites, predators and pathogens as well as man's intervention combine to limit population growth.

The following table shows how such factors influence the mortality rate of bertha armyworm.

Per cent mortality from various causes during the life of the bertha armyworm. Data from a 1973-75 study done in Manitoba.

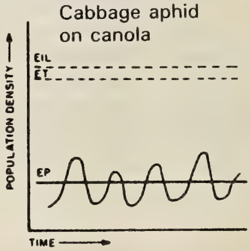
Stage	Cause of mortality	Per cent mortality	Cumulative survival (%)
Egg	Weather, predators diseases	14	86
Early to mid larva	Weather, predators diseases	18	71
Late larva	Physiological, at pupation	12	
	Parasites	62	
	Diseases	4	
		78	16
Pupa	Physiological	12	
	Cultivation injury	14	
	Low temperature	27	
		53	7
Adult	Unable to emerge from soil	50	3.5

The chief natural enemy of the bertha armyworm is a parasitic wasp whose larva lives inside the caterpillar but does not kill it until the caterpillar is nearly full grown. Notice that parasites destroyed 62 per cent of late-stage larvae. Sixteen per cent of the original population survived to pupate. Of this remaining 16 per cent, 12 per cent died of ''unknown'' causes, 14 per cent died from injuries suffered during tillage and 27 per cent from winter cold. Only 3.5 per cent survived to the adult stage, but this was probably enough to allow for a population increase in the next generation. Clearly, a small change in the effect of any mortality factor can make a significant difference in the number of survivors. By seeding early or using some other cultural control the farmer likely can further reduce the survival rate of bertha armyworm.

Natural mortality often reduces the population below the economic threshold. Populations have an average equilibrium position despite the temporary interventions of pest control. The following figures show examples of how population fluctuations can be related to economic levels.

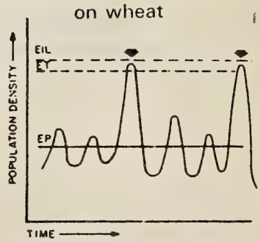
- Many insect species feed on cultivated crops without ever reaching densities high enough to cause economic injury and consequently are rarely noticed. Examples include alfalfa caterpillar on alfalfa, club-horned grasshopper on rangeland and cabbage aphid on canola.

Cabbage aphid on canola



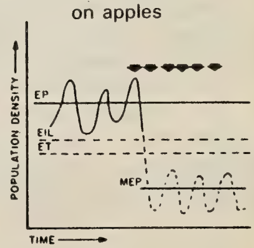
- Other insects are occasional pests exceeding economic injury levels only when their population densities increase because of unusually favorable weather. Examples include forest pests such as fall webworm which becomes epidemic in 5 to 10 year cycles, alfalfa looper on canola, and grasshoppers on cereals. When their populations peak, pests of this type require some sort of intervention, usually chemical, to reduce their numbers to tolerable levels.

Grasshoppers on wheat



- Insects with economic injury levels only slightly above the equilibrium position are perennial pests, and include: gypsy moth in hardwood forests in eastern Canada, grasshoppers on cereals in the driest grain-producing areas of the province, and Colorado potato beetle on potatoes. With these pests, even small population increases can cause damage. The general practice is to intervene with chemical or other control agents whenever necessary to reduce the population below the economic injury level.

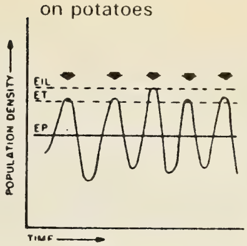
Codling moth on apples



- Insects having economic injury levels below the equilibrium position are severe pests. Examples include: codling moth on apple and European corn borer on sweet corn. Regular and constant intervention is required to produce marketable crops when pests of this group are present. Another example is western flower thrips on cucumber in greenhouses. Very low population levels of this thrips can cause extensive damage to budding florets. A complication in the control of the thrips arose when resistance to commonly used insecticides, became apparent. An integrated program using regular releases of a predatory mite, **Amblyseius cucumeris,** is now being developed.

Regardless of pest species, cooperative action by all farmers in a district will result in better control than individual action.

Colorado potato beetle on potatoes



Economic injury levels and economic thresholds for typical insect pest situations. EIL, economic injury level; ET, economic threshold; EP, equilibrium position; MEP, modified equilibrium position; pest control intervention indicated by arrows.

FACTORS INFLUENCING ECONOMIC INJURY LEVELS

Crop tolerance level - Crop tolerance is the ability of the plant to withstand insect attack. This varies with crop species and variety. All crops can better withstand insect attack when they are growing under good conditions.

Consumer tolerance level - The amount of insect damage that is acceptable to the consumer varies from crop to crop; for example, one would tolerate less damage to an apple crop than to barley or hay. The part of the plant attacked is an important consideration, since some insects may weaken the plant but leave the marketable part of the crop in good condition. If consumer tolerance of damage is low, more aggressive or costly control will be required.

The value of the crop - The farmer is more likely to consider a pest an economic threat if the crop is of high value or requires intense capital investment in its production. For instance, dryland wheat is much less intensively managed than is a crop of fresh corn.

The cost of control measures - Cost is determined by the type of control applied and the degree of control required. An error in estimating damage from an infestation can unnecessarily inflate the cost of control or even cause control to be applied when it is not necessary. Field scouting is essential to making sound decisions.

Methods of insect control

In the above section nonchemical insect control was discussed from a biological perspective: how the numbers of insects are generated and what these numbers mean in economic terms. This information on numbers allows a sound crop protection decision to be made and is especially relevant when insects are so numerous that they must be controlled with expensive chemicals. Since the intention of this guide is to provide advice to producers on managing insect pests, further references to chemical control should indicate how insecticides are to be used in combination with nonchemical methods. The methods described below can be used to reduce insect numbers and assess their impact, before serious damage has occurred. These methods are preventive as they do not compromise either yield or quality of crop. Some methods, such as mowing alfalfa to manage alfalfa weevil or pea aphid populations, are timed to allow the best quality of hay while minimizing damage. Consider the cost to benefit ratio before applying any control method; the earlier, more preventive methods are usually most cost effective.

ALFALFA LOOPER
Autographa californica (Speyer)

Host plants - Although considered general feeders alfalfa loopers prefer alfalfa, clover and lettuce. Other hosts include canola, peas, spinach, and various garden, ornamental and tree fruits. Damage to canola occurs sporadically in northern and southern Alberta.

Overwintering - Found throughout Alberta, alfalfa loopers may overwinter in the pupal stage; however, most of the Alberta population is blown in from the United States each year.

Spring appearance - Early summer moths are likely to be migrants from the U.S. The moths appear all summer long because generations overlap. Moths feed on flower nectar at dusk and fly during daylight hours.

Number of generations - There are two or three generations per year.

Pathogens - A virus disease will usually control late-season infestations.

Damage Description - Alfalfa loopers are an occasional pest in Alberta. Larvae are present from mid-June through September. Small larvae feed on leaf surfaces, medium-sized larvae eat ragged holes through leaves and older larvae feed along leaf margins and may defoliate a large portion of the plant as well as clip flowers and seed pods. The actual decrease in yield that results from this feeding damage is by no means certain. Compensation by the plant for such injuries may include continued or additional stooling, flowering, seed setting or seed plumping. Flower clipping is the most significant problem in canola but the plant can normally compensate unless severe damage occurs.

Sampling methods - Beat plants in an area one-half metre by one-half metre and record the number of larvae on the ground. Repeat this procedure several times in different locations to obtain an average number of larvae per square metre for your field.

Economic threshold - Damage occurs through defoliation and clipping of flowers and immature seed pods. No economic threshold has been established, however, more than 15 larvae per square metre, (damage assumed to be similar to bertha armyworm) combined with heavy defoliation or flower and pod clipping, may warrant control.

Management strategy

Cultural - Avoid growing canola near alfalfa.

Biological - If an infestation occurs, assess the damage to plants and sample to determine number of larvae. Delay spraying as long as possible to allow diseases an opportunity to control the pest. Historically, the pest has been adequately controlled by virus diseases.

ALFALFA WEEVIL
Hypera postica (Gyllenhal)

Host plants - Alfalfa is the main crop injured by alfalfa weevils but they may feed upon various clovers, sweet-clover and vetches.

Overwintering - Adults overwinter in protected areas often outside of fields, such as windbreaks, wooded areas and under debris along fencelines. They may also survive under grass trash in fields, or in the crowns of alfalfa. Severe winters are believed to cause high mortality or, alternatively, cold springs prevent oviposition.

Spring appearance - In the spring after alfalfa has started to grow, adults take flight in search of food plants and egg-laying sites. Females chew holes in stems, insert the tips of their abdomens into the holes, and lay a cluster of eggs in each hole.

Number of generations - There is one generation per year.

Parasites - A small wasp, **Bathyplectes curculionis**, is important in biological control of alfalfa weevil. In the past, this parasite was one of the main factors keeping the weevil under control in Alberta.

Predators - A predatory wasp, recently discovered in southern Alberta, may be beneficial in alfalfa seed fields. Damsel bugs feed on the weevil larvae.

Economic importance - Alfalfa weevil has caused important damage, especially to seedling stands, but its real economic importance is not clear. Larvae feed on the growing tips of plants and later on leaves where they eat all but the main veins. They can destroy whole fields when sufficiently abundant. The species' first appearance in Canada was in Alberta and Saskatchewan in 1954. It spread rapidly in southern Alberta and caused economic damage within four years.

Damage Description - Both larvae and adults of this weevil feed on alfalfa. In spring, adults emerge from winter hibernation to feed on new shoots. Most damage to alfalfa fields is done in late spring and summer by the larvae, which feed inside leaf buds at the tips of stems and later attack the leaves. In a heavy infestation, the leaves are so badly shredded that the field takes on a frosted appearance.

Adults cause scars on shoots by feeding and leave puncture holes in shoots during egg-laying. These punctures are visible to the naked eye and indicate the level of egg-laying activity. Newly hatched larvae will feed for three or four days inside the stem before moving up the plant to feed on developing leaf buds. Young larvae severely damage shoot tips by feeding within the folded leaves but the damage is not readily seen. Older larvae feed on open leaves and skeletonize them, leaving only veins and stems. Defoliation is most severe toward the terminals giving the entire field a grayish or frosted appearance. Notched leaves are characteristic of damage by weevil adults.

Damage is most severe to first-cut alfalfa but damage to second-cut alfalfa also occurs where the insect has been present for a number of years. When the first hay crop is cut, the larvae drop into the stubble and concentrate under the windrow for protection. While under the windrow, they feed on buds of the alfalfa crowns, retarding growth of the second crop.

Alfalfa weevil infestation can reduce hay yield by 50 per cent and the quality of hay is reduced. Feeding damage may also greatly reduce yields of seed fields.

Sampling methods - Early in the season, field inspections to determine weevil population size and stage of development are the first steps to a successful control program. The number of weevils or egg punctures will indicate the pest's presence and expected damage.

To determine the number of weevils later in the season, sample the top 20 cm of the crop with a sweep net. Take sweeps in different parts of the fields. Calculate the average number of adults per sweep.

Economic threshold - Alfalfa hay crops - 20-30 larvae/sweep for 12 per cent leaf loss; 50-75 larvae/sweep for 30 per cent leaf loss; 46 larvae/stem at peak of larval population for a return on treatment costs. Alfalfa seed crops - 20-25 larvae/sweep (90° sweep) or when 35-50 per cent of foliage tips show damage.

Management strategy

Cultural - Early cutting of first growth alfalfa (late bud to first bloom) when larvae are present will reduce populations of new adults, but this is not always practical. Green chopping, instead of cutting, windrowing, and baling can result in seasonal reductions of about 50 per cent in total numbers of weevils. However, the stubble should be checked three to five days after cutting for signs of regrowth. If green-up does not occur, determine the cause of the problem. A stubble treatment with insecticide may be necessary to control surviving larvae.

Proper soil fertility which will promote more vigorous stands will also lessen the impact of larval feeding.

Biological - In Alberta this species is attacked by a parasitic wasp which was introduced into the United States in a biological control program attempt.

ARMY CUTWORM

Euxoa auxiliaris (Grote)

Host plants - Army cutworm larvae eat the foliage of wheat, oats, barley, mustard, flax, alfalfa, sweet-clover, peas, cabbage, sugar beet, various weeds (notably stinkweed) and grasses.

Overwintering - The female moths each lay about 1,000 eggs in soft soil in late August through October, these hatch in a few days to two weeks. The larvae feed aboveground on plant foliage at night and remain below ground during the day. Development stops when the ground freezes; larvae are usually about half grown by this time. They remain inactive in loose soil just beneath the surface throughout the winter.

Appearance times - In April, larvae begin to feed again until pupation in May to early June. Moths appear in June for a brief flight period, aestivate (summer hibernation) in buildings and under trash and clods during June and July, then become active again for the egg-laying period.

Number of generations - There is one generation per year.

Natural enemies - Little is known of the natural enemies of the army cutworm. Five or possibly six species of wasp parasites have been recorded from Alberta mostly, but no recent studies of parasitism have been made.

Damage Description - Damage can be of any severity up to complete defoliation. In severe infestations, the area defoliated has ranged in size from an individual field to thousands of acres with larval densities of 200 per square metre. The first signs of damage are holes in leaves and semi-circular notches eaten from the edges of leaves.

Sampling and monitoring methods - Army cutworm moths have been monitored in southern Alberta using pheromone traps since 1978. Sampling for numbers of larvae in a field is accomplished as for other subterranean cutworm species. Mark an area of soil 0.5 metre by 0.5 metre running with the rows. During the day, larvae should be found within the top 5-7 cm of soil. Count the number of larvae within each 50 cm of row in the quarter square metre. Repeat the process in different areas of the field.

Economic thresholds - Economic thresholds for this insect have not been vigorously tested, however the following guidelines may be helpful.

The economic threshold is dependent, among other factors, on the crop infested. Mustard is more susceptible to damage from this cutworm than are cereals and alfalfa. A density of five cutworms per square metre (less than 0.5 cutworm per square foot) is sufficient to destroy a mustard field, whereas cereals and alfalfa can withstand cutworm populations of up to 50 per square metre (5/square foot). The latter crops can resume growth after attack whereas mustard cannot.

Other factors affecting the economic threshold are the plants' growth condition and the number of weed hosts in the field. A weedy field will suffer less damage than a clean one. Forage crops and pastures must be watched closely in April and early May for the presence of these larvae. Plants which have adequate moisture and are vigorously growing with 12 to 15 cm of top growth can withstand four larvae per 30 cm of row without loss of yield. If plants are under 10 cm in height and two or more larvae per 30 cm of row are present, chemical treatment is required.

Management strategy

Effects of weather - Precipitation is important: each outbreak year is usually preceded by a year with an abnormally dry July and wet autumn; A July with less than 3.8 cm of rainfall and a mean temperature of 17°C is favorable to an increase, but does not mean an outbreak in the following year unless the dry July is followed by a total of over 11.4 cm of precipitation in August to October, with most of it in September. A wet July reduces pest numbers by drowning aestivating moths or by covering them with mud. A dry fall delays egg-hatching by up to two months, kills eggs, and kills first instar larvae in the soil as they are very susceptible to desiccation. Because of these mortality factors an abundance of moths in early fall does not necessarily mean a cutworm outbreak the following year.

Cultural - Spring crops can escape damage when they emerge after the cutworms have pupated. This happens when cutworm development is advanced by favorable fall or spring weather or when crop seeding is delayed by wet weather or deliberately to avoid attack by this pest.

Mechanical - If cutworms are marching, plow a steep-sided trench across the path of the march. Lining the trench with plastic sheeting will ensure that larvae will not climb out of the trap. Insecticidal control of larvae in this limited space is economical.

BEET WEBWORM

Loxostege sticticalis (Linnaeus)

Host plants - The beet webworm attacks a wide range of broad-leaved field and garden crops. These include sugar beets, canola, flax, sunflowers, alfalfa, mustard, cabbage, carrots, beets, lettuce, onions, potatoes and asparagus. Lamb's-quarters and Russian thistle are also favorite host plants. The larvae rarely attack cereals, though they can cause alarm by marching through cereals in search of more suitable foods. This insect is found throughout Canada but is most common on the prairies.

Overwintering - These insects overwinter as mature larvae in silk-lined cells in the soil. They pupate in these cells in late spring.

Appearance times - Moths from the overwintered generation appear in late May, June or early July. They are night-active moths but if disturbed will fly readily from their daytime hiding places. Female moths lay eggs on the underside of plant leaves. Larvae appear in June and July, and adults emerge in July and August. Larvae of this second generation are active in August and September; they then prepare for winter as full grown larvae.

Number of generations - There are two generations per year.

Parasites - The webworm is attacked by a number of species of parasitic insects which can reduce the numbers of second generation moths. The nature of the soil in which cocoons are placed can influence the degree of attack by one species of parasite: cocoons in sandy soil are more frequently parasitized than those in heavy clay because they are more frequently exposed by wind and rain and more readily penetrated by the parasite's ovipositor. However, the importance of natural enemies in the population dynamics is uncertain; probably, direct effects of weather are more important.

Predators - Franklin's gull and crow are reported to have fed on beet webworm.

Economic importance - This insect has been recorded as causing economic damage somewhere in the prairie provinces almost every year since 1917. In any one area, however, it is a sporadic pest.

Damage Description - In the prairies, beet webworm is known primarily as a pest of canola, flax and sugar beet. On hatching, beet webworm larvae spend most of their time on the underside of leaves eating holes in them. Eventually, only the heavy veins may remain.

Larvae can eat the leaves of canola quickly and may then chew into seed pods or strip surface tissue from pods or stems. This gives the crop a whitish appearance. Crops with light infestations may suffer reduced yields from pod peeling. On flax, larvae eat leaves, flowers and patches of bark from the stem but rarely chew into green immature bolls. On sugar beets, young webworms feed on the underside of leaves. Older webworms eat holes through leaves and sometimes leave only ragged veins. From a distance, a heavily infested sugar beet field looks slightly brown and has a feathery appearance.

Damage often occurs to crops when starving larvae march from adjacent weedy fields or from other infested fields which have been harvested or mowed. The most serious damage to crops is caused by larvae of the first generation.

Sampling methods - For canola and most other hosts, beat the plants in an area 0.5 m by 0.5 m and count the number of larvae knocked to the soil. Repeat the process three times short distances away to obtain a total number per square metre. Sample different parts of the field to obtain an average number per square metre.

For sugar beet, count the number of webworms per leaf.

Economic threshold - Economic thresholds on canola are similar to those for bertha armyworm. On sugar beet, control measures should be taken when counts of webworms reach one or two per sugar beet leaf on more than half the leaves.

Management strategy

Effects of weather - In general, years in which beet webworm is most important as a pest are years of relatively dry, hot summer weather. The weather certainly increases its importance as a pest as weeds dry up causing larvae to march. Probably it also increases the actual numbers of the pest. Larvae destroy foliage more rapidly than usual in hot weather. In some drought years, however, weeds have dried up so quickly that larvae died, mainly from starvation.

Cultural - To reduce the likelihood of infestation, keep fields and gardens free of weeds.

Sugar beets, canola and flax should be checked thoroughly for eggs and young larvae if moths are readily observed in the field. However, large flights of moths are not always followed by high numbers of webworms.

Biological - Although parasites help keep the webworm under control, when a field becomes heavily infested only the use of insecticides will satisfactorily control the problem.

BERTHA ARMYWORM
Mamestra configurata (Walker)

Host plants - Bertha armyworm is currently known as a pest of canola in the Prairie Provinces. It also has been reported to attack a large number of other plants including turnips, potatoes, alfalfa, sweet-clover, beans, peas, tomatoes, garden vegetables and various flowers. However, these other plants are generally not good food for the larvae and feeding on these plants occurs only after the large larvae have defoliated suitable food plants (e.g., lamb's-quarters). They do not feed on cereal crops.

Overwintering - Bertha armyworms overwinter as pupae in the soil.

Spring appearance - Moths emerge from overwintered pupae. The flight period generally extends from June 25 to July 15 in southern Alberta and is somewhat later in the Peace River district.

Number of generations - There is one generation per year.

Predators - Various birds, small mammals and insect predators feed on pupae exposed during fall or spring tillage.

Parasites - The two main parasites of bertha armyworm, the ichneumon wasp, **Banchus flavescens**, and the tachnid fly, **Athrycia cinerea**, overwinter in the soil within the pupal case of their host. In a study of overwintering mortality, it was found that cocoons of **B. flavescens** were less affected by tillage than were host pupae. The number of cocoons was the same in untilled and tilled soils, suggesting that exposed cocoons were not eaten by predators. In 1973-74, overwintering mortality of **B. flavescens** was 57 per cent in untilled and 80 per cent in tilled soil, about the same as for bertha armyworm.

Puparia of the parasitic fly, **A. cinerea**, were too small to be accurately assessed from soil samples, but the number of adults emerging in the spring in one field indicated that this parasite's survival is also reduced by tillage. Insect parasites may kill up to 75 per cent of the armyworms. Unfortunately, larvae are often not killed until after they have damaged the host crop. Nuclear polyhedrosis virus, another natural enemy of bertha armyworm, kills many larvae during outbreak periods as will fungal pathogens **(Entomophthora)** if weather conditions are suitable.

Economic importance - Bertha armyworm is a perennial pest of canola. Minor infestations have been reported ever since canola was first planted on the Prairies. In 1971 through to 1973, a severe outbreak occurred and a total of 1.75 million acres of canola were sprayed to control bertha armyworms.

Damage Description - Larvae chew irregularly shaped holes in foliage but the main damage is caused by older larvae reducing seed yield as they chew into pods. In outbreaks, up to a quarter of the pods in individual fields may be destroyed. A larval population of about 200 per square metre (20 per square foot) can reduce seed production by about half. A population of 20 larvae/m^2 consumes about 65 kg seed/ha. Similarly, larvae can harm flax by feeding on the leaves, but the chief damage results from chewing into bolls or chewing through stems below the bolls so that they fall to the ground. Damage to flax and crop hosts other than canola does not normally occur, however, until larvae have consumed the cruciferous weeds in the field. On cabbage, larvae eat the foliage and bore into heads and in some years and places have caused more damage than imported cabbageworm.
than imported cabbageworm.

Monitoring methods - In 1985, the province of Alberta, in cooperation with Agriculture Canada Lethbridge Research Station, established a province-wide monitoring program for bertha armyworm and four cutworm species. Information on moth numbers is available from district agriculturists' offices.

From records of bertha armyworm flight monitoring programs, it is known that moths can be on the wing at any time during June and July but late June to mid-July is most likely. The best time to set out traps will depend on spring weather and trap location. The traps became commercially available in Alberta in 1987. Putting them out for the period June 20 to July 20 will allow you to monitor the moth flight in your location. Your records of numbers of moths trapped will allow you to make timely and accurate management decisions.

Sampling methods and economic thresholds - Your decision to sample larvae may have resulted from inspections of the field or your records of pheromone trap catches. In either case, you should sample larvae by late July. The bulk of the larval population will not have moved into the fifth and sixth larval stages by that time. An early decision to spray allows you ample time to prepare. It is unlikely that natural enemies will intervene at this stage to prevent damage. Bertha armyworm larvae have several parasites and diseases but they don't kill the larvae until growth is complete or nearly so.

The following guide to sampling has been developed for bertha armyworm on canola in Alberta. It should assist producers to make the best decision.

Step 1 - Before taking samples, determine the economic threshold for your particular situation from the table below. For example, if you can get $9 per bushel for your crop and spraying will cost $10 per acre then 19 or more larvae per square metre will lead to an unacceptable crop loss.

Economic thresholds for bertha armyworm in canola in larvae/m²*

$ Cost of spray		$ Value of seed to producer							
per ac	per ha	per bushel: / per tonne:	6 / 265	7 / 309	8 / 353	9 / 397	10 / 441	11 / 485	12 / 529
9	22		26	22	19	17	16	14	13
10	25		29	25	22	19	17	16	14
11	27		32	27	24	21	19	17	16
12	30		34	30	26	23	21	19	17

* Values are based on an average of 20 larvae/m² consuming the equivalent of 65 kg canola seed/ha (1.16 bu/ac).

Step 2 - Sample the field for armyworms. Take three samples, spaced at least 50 paces apart and at least 50 paces away from the edge of the field. Each sample is the number of larvae in a quarter square metre area of crop. Count and record the number of armyworms in each sample. The best way is as follows: shake the plants vigorously so that larvae fall into the sampling area, then count the armyworms on the ground. Make sure to look beneath leaf litter and clumps of dirt.

Step 3 - Calculate the total number of armyworms found. Add together the number of armyworms counted in the three samples taken to determine the total.

Step 4 - Use the decision table following this paragraph to determine if control is needed. Determine the range in which your economic threshold lies (Column A) from Step 1. Read across from the total number of samples taken (Column B). Find the column in which your total number of armyworms sampled lies (the total from Step 3). If your sample total lies in Column C, you have no problem. If your sample total lies in Column D, you must take three more samples. Add together the numbers of all armyworms sampled (for example, from samples 1, 2 and 3 plus samples 4, 5 and 6) and so on. If a decision still cannot be made after nine samples, the number of armyworms in the field is very close to the threshold level. Under these circumstances, spraying would be recommended if the crop will not be swathed for at least a week. If swathing time is closer, don't spray. If your sample total lies in Column E, your field (or the infested part of it) needs to be treated.

Decision table for bertha armyworm sampling

Economic threshold (armyworms per m²)	Total number of samples	Total number of armyworms sampled		
A	B	C	D	E
		Treatment not required	More samples required	Treatment required
13 - 17	3		0 - 94	95 or more
	6	less than 21	21 - 159	160 or more
	9	less than 50	50 - 220	221 or more
18 - 22	3	less than 2	2 - 118	119 or more
	6	less than 37	37 - 203	204 or more
	9	less than 29	79 - 281	282 or more
23 - 27	3	less than 8	8 - 142	143 or more
	6	less than 55	55 - 245	246 or more
	9	less than 108	108 - 342	343 or more
28 - 32	3	less than 14	14 - 166	167 or more
	6	less than 73	73 - 287	288 or more
	9	less than 138	138 - 402	403 or more
33 - 37	3	less than 24	24 - 186	187 or more
	6	less than 96	96 - 324	325 or more
	9	less than 175	175 - 455	456 or more

Management strategy

Cultural

Effects of tillage and snow cover - To improve the control of bertha armyworm a study was conducted of the effects of fall cultivation on survival of pupae.

Samples of both armyworm and parasite pupae were collected in the autumn and spring of 1973-74, 1980-81 and 1981-82. These were taken from untilled and tilled portions of 12 fields of canola (**Brassica napus** and **B. campestris**) in the Dauphin and Swan River districts of Manitoba. From these samples the mortality caused by various factors was determined.

Tillage, which differed among fields, was with deep tiller, disc, or mold-board plow. Some fields were then harrowed. The type of tillage equipment or soil did not affect pupal survival.

Survival did vary among fields, however, from 24-90 per cent in untilled soil and from 0-38 per cent in tilled soil. In untilled soil, most deaths occurred during winter (they were higher in 1980-81 and 1981-82 than in 1973-74. Tillage caused 16-75 per cent mortality, with an average of 51 per cent for all fields. Deaths were of two types: from injuries caused by tillage and by disappearance probably caused by gulls and crows feeding on pupae that had been turned to the surface.

Average number of bertha armyworm pupae in the autumn and spring and the percentage of mortality during autumn, winter and through tillage[1].

	1973-74		1980-81		1981-82	
	No Tillage	Tillage	No Tillage	Tillage	No Tillage	Tillage
Pupae/m², autumn	3.4		29.8		6.4	
Dead, autumn	20%	21%	2%	1%	4%	8%
Dead, tillage	0%	54%	0%	40%	0%	43%
Dead, winter	7%	7%	42%	47%	51%	64%
Pupae/m², spring	2.5	0.6	16.6	3.8	2.8	1.1

[1] In two fields during winter of 1973-74 and five fields in each of the winters of 1980-81 and 1981-82, in Manitoba.

Snow depth affected overwintering mortality; the greatest occurred when snow accumulation was light. In 1973-74, for example, accumulation was heavier than during the other two winters. Mortality was lowest with deep snow cover and reached 100 per cent with less than 3 cm accumulation. It was generally greater in tilled soil because the lack of stubble led to less snow accumulation.

Additional mortality occurred among pupae that survived the winter. In one field, comparison of the number of emerging adults with the number of pupae surviving the winter showed mortality of 27 per cent in untilled and 75 per cent in tilled soil. This may have been due to delayed effects of cold stress plus disturbance of the soil by tillage, which made reaching the soil surface difficult for newly emerged adults.

The study found that fall tillage reduces the numbers of overwintering bertha armyworm pupae. The amount of snow cover will also affect pupal survival. The parasites of the pest were also affected by tillage, but to a lesser degree.

Variety selection - Argentine and Polish cultivars of canola and other host plant species have been tested for their effects on growth, reproduction and survival of bertha armyworm. Although there are some slight differences in the insect's physiological responses to the canola cultivars, there is some evidence that behavioral responses differ. Egg laying females are most attracted to canola at early bloom. Polish cultivars have a shorter bloom period and are therefore less likely to have this susceptible stage present during the peak of moth activity.

The date to maturity period depends upon the cultivar and can influence susceptibility of the crop to infestation. This should be considered along with economic, harvest time and other criteria. Over the province as a whole, Polish varieties mature about 13 days earlier than Argentine varieties and may be harvestable before significant damage occurs. Maturity can vary considerably, however, depending on location, weather and date of seeding.

Seeding date - By selecting an early maturing variety and seeding early you can avoid the bertha armyworm problem altogether unless moth flight is exceptionally early. Indeed, canola harvested before August 15 is unlikely to suffer yield loss from bertha attack. The bertha flight period generally extends from June 25 to July 15 in southern Alberta and is somewhat later in northern Alberta. Mated bertha armyworm females prefer to lay eggs on canola in the early bloom stage. Fields in this stage during the egg-laying period tend to be hardest hit. This is at least part of the reason why infestations tend to be spotty even within a local area. Each field must be inspected and the infestation level is likely to vary significantly from field to field.

Biological

Most major infestations were terminated by virus diseases that destroyed larvae in large numbers. The species is attacked in British Columbia by four species of parasitic insects and three kinds of pathogenic viruses. A field study in Saskatchewan, apparently between infestation periods, showed eight per cent mortality of eggs and larvae, with parasitism responsible for about half the larval mortality.

CANOLA ROOT MAGGOTS

Delia (spp.)

Host plants - Root damage to canola crops in Alberta is caused mainly by the cabbage maggot, **Delia radicum** (L.) except in northeastern Alberta where the turnip maggot, **D. floralis** (Fallen) becomes the most numerous species. Both these species also infest other cole crops, including rutabaga, cabbage, mustard and radish.

Overwintering - During the second half of July larvae leave the roots to pupate in surrounding soil. The puparia are reddish brown in color, 6-7 mm long.

Spring appearance - In northern Alberta, adults of the cabbage maggot emerge from overwintering puparia from about May 15 to July 15 with most emerging during June.

The life history of the turnip maggot in northeastern Alberta is similar, but emergence of adults from overwintering puparia does not begin until the first week of June, about two weeks later than the cabbage maggot.

Number of generations - In northern Alberta, the cabbage maggot has one generation. A few new adults emerge during the same season and no second generation of larvae is found on canola. On irrigated land in the Lethbridge area, however, there are two generations of cabbage maggot, with peaks of oviposition in June and again in late August to early September.

The turnip maggot has only one generation throughout its Alberta range.

Predators - The most important predators of the immature stages of root maggots are believed to be both larvae and adults of ground beetles and rove beetles. The most abundant species of ground beetles in canola fields in northern Alberta are **Bembidion** species, which are known to feed on root maggot eggs. The feeding habits of the several species of rove beetles common in these fields have not been studied but it is likely that some (especially as larvae) are predators of root maggots, the most abundant potential prey during July.

Parasites - Insect parasites attack a specific stage of the host. Parasites of the puparia of root maggots are found in Alberta (e.g., Aleochara rove beetles and a small parasitic wasp, **Trybliographa**) but their incidence in canola fields appears low. It is suspected that they do not follow the rotation of canola crops as efficiently as does the cabbage maggot, since they are not specific for cabbage maggot and also attack other insects on cole crops.

Adult flies may be infected by two species of parasitic fungi, **Entomophthora** and **Strongwellsea. Entomophthora** infection causes quick death and flies so killed may be recognized by the eruption of fungal hyphae through the membranes of the abdomen. A wide range of flies is susceptible to this disease. The **Strongwellsea** fungus is specific to root maggots and may achieve high rates of infection. Infected flies may be recognized by the presence of spores discharged into their abdominal cavities by the fungus. Although infected flies are not killed, the females are unable to mature eggs.

Economic importance - While plant mortality is normally low, mortality of 40 per cent was documented southwest of Westlock in 1983 as a result of the combined effects of maggot feeding and root rot under persistently wet soil conditions.

Province-wide surveys of damage to canola by root maggots, chiefly the cabbage maggot, indicated that crop infestations were higher in those areas of Alberta where cooler temperatures and higher moisture conditions prevailed. These conditions promote maggot survival and development, and are common in the northwest and Peace River regions. In the northwest, an average of 75 per cent of roots in a field were infested in 1981, 34 per cent in 1982, 64 per cent in 1983. In the Peace River region the average was 31 per cent in 1981, 15 per cent in 1982 and 25 per cent in 1983. In the remaining regions combined, an average of 5 per cent of the plants in a field were infested in 1981, 13 per cent in 1982, and 16 per cent in 1983. Most infested roots were scarred on the surface only. However, tunnelling throughout the roots and occasional plant death were observed also. In southern Alberta, maggots are a problem only on irrigated land.

Damage Description - Maggot feeding on canola typically produces irregular vertical furrows on the main rootstock. The effect on yield of nonlethal feeding by low numbers of larvae is still uncertain and under investigation. Feeding by 3 or more larvae may girdle plants, interrupting the supply of water and nutrients to aerial parts. Scars caused by maggot feeding are often invaded by fungi, especially **Fusarium,** from surrounding soil. While canola plants can resist this infection under good growing conditions or low maggot numbers, field observations suggest that resistance may break down if wet soil conditions favorable to fungal growth prevail during July. In such cases, the plants wilt and finally break off just below ground level owing to the combined effects of maggot feeding and root rot.

Damage caused by larval feeding accumulates from late June to the end of July, by which time most larvae have pupated and damage for the year is more or less complete.

Insect Control

Monitoring methods - Adult flies can be readily netted or trapped in yellow bowls of water set around field margins. However, their identification requires expertise, as many similar species of flies are attracted to canola fields when the crop is in flower.

Sampling methods - Good eyesight or a hand lens is necessary to check whether eggs are being laid in mid to late June by inspecting the bases of stems and surrounding soil. The degree of larval infestation and resulting root damage can be determined by inspecting rootstocks from late June through July. To avoid dislodging larvae and damaging rootlets, cut a 5 cm core of soil around the roots with a knife; lift the plant and count the larvae on the roots while removing the soil. A less time-consuming procedure, if only a damage assessment is needed, is simply to pull the plants while grasping the base of the stem. Brush off the soil and inspect the rootstock for scarring caused by maggot feeding. The best time for assessing cumulative damage for the season is the last week of July. During August, damage may be underestimated because killed plants are no longer obvious.

Sometimes it may not be apparent whether dead or dying plants with their rootstocks rotting or broken off were first attacked by root maggots or were invaded by rot fungi without prior maggot attack. To determine whether maggots were present, scoop out the soil surrounding the roots to a depth of 10-15 cm with a trowel and spread this soil on the ground; if root maggots were present, you should find their puparia.

Estimates of the population of puparia overwintering in fields can be made after the crop has been cut (but before cultivation) by turning over the soil within a square metre area with a trowel following a random sampling plan.

Economic threshold - Not established, however, it appears that feeding by three or more maggots may girdle plants, interrupting the supply of water and nutrients to above ground parts.

Management strategy

Cultural - The effect of different cultural practices on the level of root maggot infestation has not been investigated. Crop rotation is unlikely to have much effect, since the flies habitually disperse from fields in which they emerge and locate new crops by odor.

CLOVER CUTWORM
Discestra trifolii (Hufnagel)

Host plants - Clover cutworm larvae are above-ground feeders on the foliage of most vegetables, flax, canola, sunflowers, alfalfa, clover, peas, beans and sugar beets. Numerous weed species complement the clover cutworm's diet: Russian thistle, lamb's quarters and redroot pigweed are among those reported.

Overwintering - The species overwinters as pupae in the soil.

Spring appearance - Overwintering cutworm pupae emerge as moths from the end of May through June with the peak being in the first half of June. (Dates are for southern Alberta populations and may vary by one or two weeks: later in the north or when springs are cool.)

Number of generations - There are two generations per year. Moths of the second generation appear in late July or August.

Economic importance - Clover cutworm is a recurrent problem in canola grown in the Peace River region and is a sporadic pest of truck crops and sugar beets in the south. Clover cutworm infestations on canola were prevalent in the Peace River area in 1982; the insect is generally not present in economically injurious numbers.

Damage Description - There are two generations of clover cutworm in Alberta. Eggs are laid on the underside of leaves in late spring and during summer. Newly hatched caterpillars feed on the underside of lower leaves, gradually moving up the plant as they mature. Damage from the first generation may be expected from approximately late June through July and that from the second generation from mid-August through September.

Second generation clover cutworm larvae may be present at the same time as bertha armyworm larvae. While bertha armyworms tend to be dispersed throughout fields, clover cutworms have a more clumped distribution and so damage is more concentrated.

Larvae eat the foliage and pods from canola plants and, when present in high numbers, will strip plants completely. Larval infestations and adult flights tend to be localized with apparently suitable nearby habitats remaining undisturbed. Shortage of food, a result of severe infestation, will cause larvae to march en masse into nearby fields.

Sampling and monitoring methods - Clover cutworm is one of five cutworm species being monitored with pheromone traps. Since it is a recurrent pest of canola in the Peace, provincial monitoring of this species is limited to that area.

Sampling to determine numbers of larvae is accomplished by beating plants in an area one-half metre by one-half meter and recording the number of larvae on the ground. Repeat this procedure several times in different locations to obtain an average number of larvae per square metre for your field.

Economic threshold - The economic threshold for this insect is probably similar to that for the bertha armyworm. (See the bertha armyworm section to determine thresholds from sampling data). Second generation larvae frequently cause damage at the same time as bertha armyworm and in years when both species are present, clover cutworms may be mistaken for bertha armyworms.

Management strategy

Cultural - Normal rotation of canola with cereal crops will minimize infestations because adult dispersal to new areas is slow. Fall plowing will expose pupae to predators and freezing.

Biological - Parasites, predators, disease and inclement weather have checked past infestations of clover cutworm on canola grown in the Peace River region. High mortality from such natural causes after a short period of high population density is common for the climbing cutworms.

DARK-SIDED CUTWORM

Euxoa messoria (Harris)

Host plants - The dark-sided cutworm can cause serious damage to seedlings and transplants of most vegetables and field crops. Plants attacked include peas, beans, potato, tomato, cucumber, melon, sweet pepper, asparagus, alfalfa, corn, barley, strawberries and spruce seedlings. Older records, which may or may not refer to this species, include oats, onions, crucifers, and clover. Occasionally the damage can be locally significant.

Overwintering - Eggs overwinter in cultivated fields on the soil beneath plants and debris.

Spring appearance - Larvae hatch from overwintered eggs during the first period of extended warm weather in spring. During the day, larvae remain in the soil at the base of plants on which they feed at night. Mature larvae pupate in the soil. Moths are active from late July to early September.

Number of generations - There is one generation per year.

Damage Description - Larvae feed on emerging plants at or below the soil surface. They may completely consume above-ground portions of small plants, especially the succulent ones that have been transplanted recently. These larvae may even climb trees to injure buds. Crop damage is most severe from May 15 to the end of June.

Sampling and monitoring methods - Dark-sided cutworm is one of five species monitored throughout the province with pheromone traps. This provincial monitoring program began in 1985.

Management strategy

Cultural - Weed control and the destruction or ploughing under of crop trash soon after harvest, preferably before August, will help to reduce egg laying.

DIAMONDBACK MOTH
Plutella xylostella (Linnaeus)

Host plants - A sporadic pest of cabbage, cauliflower, brussels sprouts, broccoli, turnips of various kinds, mustard, rape and canola, the diamondback moth also feeds on several species of related weeds (mustard family). It does not attack cereals.

Overwintering and spring appearance - The diamondback moth does not overwinter in Alberta but is carried on winds from the United States each spring. The number of spring migrants and their establishment is weather dependent, so advance forecasts of early infestations are not possible. By late summer most canola fields are infested to some extent. The population ecology of this species in Canada has been particularly well studied. The size of the first immigration, whether or not there are additional immigrations, and the size of each, are factors that determine the potential abundance each year. The availability of suitable food for first generation larvae may also be important.

Number of generations - There are three generations of moths annually, the first migrating from the United States in early May or June. The moths are weak fliers and easily carried by the wind. Later in the summer, generations overlap so that all stages may be found on host plants at the same time.

Predators - Include mites, spiders, lacewings, predatory plant bugs and three species of birds.

Parasites - No egg parasites have been found. At least 10 species of parasitic insects attack the larvae and pupae in Ontario; the most important of these kill an average of 50 to 60 percent.

Pathogens - Disease seems to be a negligible cause of death.

Damage Description - Damage done by young larvae to canola is characterized by small holes and surface stripping on the undersides of leaves as well as small white mines in the leaves. Older larvae feed on flowers, young pods, and surface tissue of stems and mature pods, usually from mid-July to early August.

Yield losses are caused by feeding on the surface of filling and maturing pods. Seeds under these damaged areas do not fill properly and the pods are more susceptible to early shattering. In severe cases, feeding damage shows from a distance as an abnormal whitening. After an infestation is controlled in a podded crop, a new infestation is not likely to become established because of the rapid advancement of the crop toward maturity.

In general, it is the second generation larvae which cause yield loss and only when it coincides with peak flowering to early podding stages of canola (often about the last week in July). The third generation is likely to affect only unusually late maturing crops.

Although they usually attack only the leaves of host plants, older larvae often feed on the florets of cauliflower and broccoli and bore into the heads of cabbage and the sprouts of Brussels sprouts. Pupae found on the heads of wheat at harvest developed from larvae that fed on mustard family weeds or volunteer canola in the wheat field. This pest does not attack cereals.

Sampling methods - Sample by beating plants within quarter-square-metre areas and counting larvae on the ground.

Economic threshold - An average of 300 larvae per square metre may warrant control when they occur at the same time as canola pod development. Damage to pods is most severe when canola leaves have dropped. Normally the larvae feed on the leaves and do not move to pods until adequate leaf material is not available.

Management strategy

Effects of weather - A major cause of larval deaths is rainfall: larvae are washed from leaves and drown in water collecting in leaf axils or in pools on the ground. Young larvae are most affected: an Ontario study showed that more than half may die from this cause. Older larvae are affected less because they are not easily washed off and can regain the plants more readily if dislodged. A driving rain in a thunderstorm reduced a population by 74 per cent, whereas over 2.5 inches of rain as showers or drizzle caused a reduction of under 20 per cent. Larvae are more susceptible to harm by rain in cold than in mild weather. These effects of summer rain may explain why infestations appear to be more frequent in the Prairie Provinces than elsewhere in Canada.

Another factor controlling diamondback moth abundance is the weather during the egg-laying period. Cool cloudy weather reduces moth flight activity; the longer inclement weather persists, the more females die before egg laying is completed.

Tillage - Factors responsible for the potential abundance of this pest are the size of the spring immigration and the availability of suitable food for first generation larvae. If the moths arrive before preferred host emergence, alternate host plants will include volunteers and other weeds on summerfallow. Tillage reduces the availability of suitable host plants thus affecting the successful establishment of first generation larvae.

EUROPEAN CORN BORER

Ostrinia nubilalis (Hubner)

European corn borer was accidentally introduced into North America. The first Canadian record is from Ontario in 1920. The species became so important in the 1920s that the Government of Ontario passed the Corn Borer Act, which enforced the application of certain control measures. The corn borer was found in Alberta in 1956.

Host plants - Sweet corn is the preferred host but grain corn is also damaged. Over 200 other plants are recorded as hosts including, in Canada, potato, tomato, tobacco, oats, soybean, white beans, sugar beet, broom millet, hops, and various weeds and ornamental plants. In Canada, this species attacks such plants only under abnormal conditions, for example when corn is absent. However, since corn was not native to Europe, it must have developed on alternate hosts and adapted to corn over time.

Overwintering - European corn borers overwinter as fully grown larvae in corn stalks, cobs and plant debris on the soil surface.

Spring appearance - In late spring the larva chews an exit hole from its overwintering cell in plant debris and then returns to spin a cocoon in which to pupate. Beginning in mid-June, moths emerge in early morning, they fly between half an hour and four and a half hours after sundown, with a second minor flight near dawn. Wind does not prevent flight; the moths fly into a slight wind. They are attracted by light. They fly to non-hosts, such as tall grass, to find mates and begin egg development. Peak egg laying and flight occur around the middle of July. Females will lay up to 500 eggs during this time.

Number of generations - Only one generation per year has been observed in the Prairies although a second flight of adults has been detected.

Predators - European corn borer is attacked by many natural enemies throughout its life. Lady beetles and other insects and predaceous mites feed on the eggs and young larvae. Beetles entering the borer tunnels to feed on plant sap will injure borers and crowd them out of the tunnels. Downy woodpecker, ringnecked pheasant and other birds dig overwintering borers out of their chambers in cornstalks and plant debris.

Parasites - Of 17 species of parasitic wasps and flies introduced to Canada between 1923 and 1940 for corn borer control, three became established.
Native species of **Trichogramma,** a group of tiny wasps, attack the eggs of many butterfly and moth species, including European corn borer.

Pathogens - A protozoan, **Nosema pyrausta,** weakens the borer so that infected larvae suffer heavier winter kill, and infected moths lay fewer eggs than healthy moths. This protozoan plays a moderate to significant role in reducing borer populations.

Two other protozoa, **Varimorpha** species, infect the borer under laboratory conditions. One is extremely virulent and looks promising as a microbial control agent.

Beauveria bassiana, a widespread fungus, will kill more than 50 per cent of the overwintering borer population in a given year. Epizootics of **B. bassiana** occur most readily during periods of ample rainfall with temperatures around 30 °C.

The potential of the bacterium, **Bacillus thuringiensis,** as a microbial control agent of corn borer has been studied. This bacterium produces spores and crystals. In laboratory tests, both spores and crystals retarded growth of the borer. A combination of spores and crystals killed larvae. A recently registered granular formulation of **Bacillus thuringiensis** is effective on corn borer.

Nuclear polyhedrosis viruses isolated from alfalfa looper and a mint looper will infect the borer. Recent field experiments suggest viruses might show promise as control agents.

Damage Description - All above ground portions of the corn plant can be attacked. Young larvae bore into growing whorls where they feed on developing leaves, giving them an etched or shot-hole appearance. Young larvae boring in the leaf midrib will cause leaf breakage. Feeding in developing tassel stalks weakens them so they are easily broken off by the wind. Older larvae bore into stalks and ear shanks, disrupt the normal movement of nutrients and water, which then results in reduced yield. Stem breakage and ear drop are common damage symptoms. Another is boring dust or frass resembling small balls of sawdust in the leaf axils and on kernels within the ear. Feeding damage to sweet corn ears makes them unmarketable. The tunnelling and boring permit secondary infection and damage by stalk and ear rotting fungi.

Sampling and monitoring methods - Monitoring moth activity can be useful in determining duration and intensity of moth flight and when to begin field scouting. Nightly flights can be monitored by charting the number of European corn borer moths caught per night in a light trap. During the day, moths may be flushed from grassy field margins, weedy fence rows, and other areas of dense vegetation where moths congregate, mate and feed. These action sites of dense vegetation are necessary stopover points for female moths before egg deposition in the cornfield. Locating these action sites and observing moth activity can be very helpful. Research using a square metre drop-net has shown that the number of female moths in the grass around field edges, in waterways and between the rows of weedy fields correlates with the number of egg masses deposited on corn plants. Three females per square metre equals 0.5 egg masses per corn plant. With good weather, this level of infestation could mean economic losses.

Walking through the action site will cause the moths to flush. Recent research indicates the flush method correlates well with the drop-net method for monitoring adult populations. An average of 61 moths (males and females) in a distance of 1 m x 10 m (3 feet x 33 feet) of the action site is equivalent to an average of three females per square metre. A minimum of five flush samples should be taken in the grass per eight hectares (20 acres) of cornfield. This adult flushing technique is a useful way to determine whether scouting for egg masses should be started.

The best scouting methods produce estimates of the total field population. The key is taking good, representative samples. Take a minimum of five random samples of 20 consecutive plants each. The first sample should be taken after walking beyond the edge of the field to eliminate the "edge" effect. Remaining sample sites should be taken randomly across the entire field. Be careful to consider all representative topographical and other features that may influence plant height, plant maturity and plant density. If more than one variety is planted in the same field, consider each variety a separate field and sample separately. If the field is larger than 40 acres, divide the field into 40 acre blocks and consider each block a field. Record all observations.

Examine plants for shot holing in the leaves and balls of sawdust-like material in the leaf axils. Record the number of plants damaged. Dissect two infested plants per sample of 20 and look for live borers. It is important to check for live larvae since borer mortality in the first three to five days following hatch is normally very high.

Economic thresholds - The economic injury level (EIL) is the pest population density at which the value of actual or potential damage equals the cost of preventing the damage. The economic threshold (ET) is the population density at which control measures should be initiated to prevent the pest density from surpassing the EIL.

In order to apply these concepts to the European corn borer, the theory of a treatment window must be introduced. Only larvae that have not bored into the plant can be killed. Consequently, there is a specific time period, or "window", during which pesticides must be applied if they are to be effective. Because egg deposition in a given field may last two to four weeks, insecticides must typically be applied before all eggs have been deposited in a field. Otherwise, larvae from eggs deposited early in the egg laying period will succeed in entering the plant. The decision to treat, therefore, must be based on an estimate of the potential European corn borer population density in the field. The potential population density in a given field may be estimated as follows:

- Scout the field weekly for borer egg masses. Include your count of the hatched egg masses. Or, as previously described, flush the weedy areas around the field for adults.
- Begin counts of borer egg masses per plant with the first sign of borer eggs in the field. Researchers believe that it is unlikely that eggs can be detected before 5 per cent of the eggs are in the field. This assumption becomes an integral part of calculating the potential population density.
- Calculate the potential population density (PPD) per plant by:

$$\mathrm{PPD} = \frac{(\mathrm{SV})(23)(\mathrm{EM})}{\mathrm{PO}}$$

where:

SV = the average proportion of individuals surviving through the damaging stage. Based on studies from Iowa and Kansas, a value of 0.2 is recommended.

EM = the number of egg masses per plant. This is multiplied by the average number of eggs per mass (23).
PO = the proportion of the total egg complement deposited before detection in the field = 0.05.

- The field should be sampled and PPD calculated again eight days later. Assume at this time that 50 per cent of the eggs have been laid (based on an assumption of a three week egg laying period). Thus, PO = 0.5.

Although ET is usually less than EIL, in this case ET = EIL because we are making the control decision before all of the borer population is present in the field (so the insect is destroyed before it reaches the damaging stage). The ET (EIL) may be estimated as follows:

- Determine the cost of control (dollars per acre). This includes the cost of insecticide and the cost of application by ground or air.
- Estimate the market value of the crop (dollars per bushel of corn) at the intended time of sale and the crop yield (bushels per acre) at harvest.
- The ET is then calculted by:

$$ET = \frac{CC/MV}{(DL/100)EY}$$

where:

CC = control costs ($/ac),
MV = market value ($/bu)
DL = percentage damage loss (per borer per plant) at the time of infestation (percentage loss column from the table at the end of this section), and
EY = estimated yield (bu/ac).

At this point the treatment decision can be made by comparing the potential population density (PPD) to the economic threshold (ET). If PPD is greater than or equal to ET, then treatment is warranted. For example: Assume that on the second sampling date (eight days after initial borer detection and during pollen shed), you counted 15 egg masses per 100 plants sampled.

$$PPD = \frac{(SV)(23)(EM)}{PO} = \frac{(0.2)(23)(0.15)}{0.5} = 1.38 \text{ larvae/plant}$$

After talking with the aerial applicator, you determine that control costs will be $16 per acre for a single insecticide application. You estimated that the crop will yield 140 bushels per acre and that you will receive $3.40 per bushel at sale.

$$ET = \frac{CC \quad MV}{(DL/100)EY} = \frac{\$16.00 \qquad \$3.40}{(4.4/100 \qquad 140\ \text{bu})} = 0.76 \text{ larvae/plant}$$

In this example, PPD (1.38 larvae per plant) is greater than ET (0.76 larvae per plant) and treatment is economically justified.

This procedure was used in 1981 during a pilot European corn borer management program, and the proper treatment decision (based on a single insecticide application) was reached in seven of eight Kansas fields. Work in Alberta to verify results from the U.S.A. is still in progress. Potential users of this procedure must remember that virtually any factor that affects one of the variables in the equations could change the decision. Incorrect estimates of variables could cause you to reach an economically unjustified treatment decision. Assumptions concerning the length of the egg-laying period (which influences PO), the proportion of larvae surviving (SV), and the damage loss relationships (DL) are the weakest portions of the procedure.

Corn loss caused by European corn borer and calculated economic injury level for various corn growth stages.

Plant Stage	Loss, bushel per acre (ECB per plant)	Percentage loss (ECB per plant)	Calculated EIL one application	Calculated EIL two applications
Early whorl	7.7	5.5	0.61	1.22
Late whorl	6.2	4.4	0.76	1.53
Pre-tassel	9.2	6.6	0.51	1.02
Pollen shedding	6.2	4.4	0.76	1.53
Kernels initiated	4.2	3.0	1.12	2.24

CC = $16.00 per acre, 1 application; CC = $32.00 per acre, 2 applications
MV = $3.40 per bushesl
EY = 140 bushels per acre
DL = based on percentage loss in table
See text for explanation of abbreviations.

Management strategy

Cultural - Corn borer adults are strong fliers and can be dispersed by wind. Transportation of infested plant material such as corn silage or corn cobs can spread the larvae.

Cultural procedures can greatly reduce corn borer infestations. Ideally, all crop residues should be cut for silage or shredded for fodder immediately after harvest. The remaining stubble should be burned or disked and ploughed under 10-15 cm (4-6 in.). Ridging may be necessary to cut down the risk of soil erosion.

If proper cultural control cannot be implemented in the fall, the corn residue and stubble should be ploughed down in early spring (by May 1).

In areas where the corn borer is present, early planting of early maturing corn hybrids or varieties should be

considered so that fall ploughing can be carried out as early as possible.

Deep cultivation of infested fields that were ploughed down should be avoided to prevent bringing up buried corn stubble.

European corn borer was eradicated in Alberta 30 years ago by methods similar to those recommended above. Tolerant or resistant corn varieties, although available for other areas of North America, are not yet available for Alberta.

Chemical controls may be effective if applied within a few days of egg hatching and beginning of larval feeding. Once larvae enter the stalk, no controls are available. Light trapping or pheromone trapping to determine the time of moth flight, and field scouting to determine the size of egg populations and time of hatching are required to optimize application timing. More than one application may be necessary depending on the length of the adult flight and subsequent hatching period.

Recent research suggests that corn borer larval populations can be kept below economic levels by combining grass and weed control with adult moth control. If cornfields are kept relatively free of grass and dense weeds, and the waterways and field edges are mowed, corn borer moths can be "herded" into selected patches of grass and killed with nonpersistent insecticides. These trap patches of grass are necessary for fields where most grassy areas have been mowed. They would prevent resident and guest moth populations from seeking cover in untreated grass near neighboring fields and then returning to lay eggs in the fields having mowed borders and waterways.

FLEA BEETLES

Host plants - Adult flea beetles become active in early spring (April to early May), mate and feed on leaves of available cruciferous (mustard family) weeds such as flixweed, stinkweed, wild mustard, lamb's quarters, volunteer canola and pepper grass.

Overwintering and spring appearance - Flea beetles overwinter as adults under leaf litter and other ground debris in grassy headlands, fencerows and wooded areas. The three economically important species have slight differences in timing of life cycle stages; for instance, the hop flea beetle emerges earlier from hibernation and the crucifer flea beetle emerges later than the striped flea beetle. The crucifer flea beetle, **Phyllotreta cruciferae** (Goeze) and the striped flea beetle, **P. striolata** (F.), are the most persistent pests and were introduced to North America from Europe; the hop flea beetle, **Psylliodes punctulata** Melsheimer, attains occasional pest status and is most common in irrigated areas.

Number of generations - Only one generation of flea beetles is produced each year.

Parasites - Some wasp parasites of flea beetles are known but affect only a small proportion of the population.

Damage Description - Most damage to canola is done by the overwintered adult beetles just before or soon after seedlings have emerged from the soil. Flea beetles move into newly emerging canola crops from the borders by hopping when temperatures are below about 18°C, and flying when the temperature is higher. They feed by chewing small holes in the cotyledons and leaves. Damaged plants typically have a "shot hole" appearance when the tissues around the feeding sites in the cotyledons and leaves die. Losses from flea beetle feeding on young seedlings include reduced number of plants surviving, smaller and weaker plants, and delayed plant development and maturity. All contribute to reduced yield. This is especially true if the weather is hot and dry. Canola seedlings can withstand significant leaf area removal in the cotyledon stage under good plant growing conditions without significant reduction in yield. With heavy and continuous attacks, seedlings may wilt and die, particularly when feeding is combined with poor plant growth during hot, dry weather. Heavy infestations may destroy the entire crop and reseeding may be necessary. Once the crop reaches the 3 or 4 leaf stage, the plants are generally established and can outgrow the feeding damage. Also the number of adult flea beetles often begins to decline at this time.

The new generation of adults emerges in late July through early August. They skeletonize leaves and chew the epidermis from stems and pods without causing economic damage if the seeds are sufficiently developed. Late maturing canola is, however, at greater risk. In either the early or late crop stages, cool, wet weather reduces feeding activity and favors plant growth whereas hot, dry conditions promote crop damage by beetle adults.

Sampling methods - In most cases, the amount of defoliation is used as a gauge for applying controls. The key point to remember is that the amount of defoliation is frequently overestimated. Collect plants at random throughout the field and estimate the foliage damage. For example, it is established that canola seedlings can withstand 50 per cent leaf loss. Flea beetles generally invade fields from the edges, except when temperatures are above 18°C and beetles are flying. Therefore, select plants at various intervals as you walk into the field. At each location estimate leaf loss. Check all field and slough margins where the insect overwinters. This sampling procedure determines the extent and distribution of damage.

Daily inspection of newly emerged plants is necessary to identify flea beetle damage as it develops. If flea beetles are numerous on the plants or on the soil, if beetle feeding damage is in excess of 50 per cent of the cotyledon or leaf area, and if the weather is warm and dry, a foliar applied insecticide may be necessary. If damage is only along the field margins and beetles are still congregated there, then controls may be restricted to damaged areas only. Seed dressings and granular insecticides can be applied with seed to control flea beetles. This may have less environmental impact than application of foliar sprays.

Management strategy

Cultural - Very few cultural or preventive controls are available. Allowing cruciferous weeds to grow in summerfallow fields may help in reducing damage by keeping flea beatles on the fallow rather than having them move into the crops.

Cruciferous weeds and volunteer canola in cereal fields can be controlled to starve out early spring populations. In addition, in the spring leave a trap strip of volunteer canola near overwintering sites and cultivate the remainder of the field. Spray this trap strip before beetles move into seedlings.

GRASSHOPPER — Clear-Winged
Cammula pellucida (Scudder)

Host plants - The clear-winged grasshopper is mainly a grass feeder. Economic damage is primarily to cereals, especially wheat and barley. Clear-winged and migratory grasshoppers have together destroyed areas of range grass and hay almost entirely. They eat that fraction of the foliage that domestic animals prefer to eat and have destroyed cattle feed to such an extent that serious loss has often occurred.

The nutritional qualities of the chief food plant can affect longevity and egg laying. Kentucky blue grass is one of the best foods for high survival and egg laying. Western wheat grass is one of the worst and could be a factor limiting distribution of this grasshopper in the Prairie Provinces as it may be the only green grass available to attract females at egg laying time.

Spring appearance - If the preceding fall has been warm, it is likely that clear-winged grasshopper eggs will be the last of the pest grasshopper species to hatch. They hatch in late May to early June. The embryos of this species undergo a maximum of 50 per cent of their total development prior to diapausing for the winter. The other pest species can complete more of their development in the fall and consequently need less time in the spring to complete pre-hatch development.

Overwintering - Clear-winged grasshopper eggs are laid in the fall and hatch the following spring. Each female lays an average of 8 egg pods (about 175 eggs) usually in unbroken sod. The short vegetation of dry, mowed roadsides and sparse, overgrazed pastures is especially favored for egg laying. Males are conspicuous at egg laying sites - their undersides become bright yellow during the mating/egg laying period and they stake out a territory while waiting for females to come to oviposit.

Number of generations - As with all of Alberta's pest grasshopper species, clear-winged grasshoppers have one generation per year.

Natural enemies - Next to weather, natural enemies are the grasshopper's most important population controlling factor. In some localized areas natural enemies may cause even more mortality than the weather.

Some of the grasshopper's enemies attack them when they are still in the soil awaiting the coming of spring. Others attack nymph and adult stages.

Predators - Egg predators - Among the most important egg predators are bee flies, blister beetles, ground beetles and crickets. Adults of some of these insects, like the common field cricket, eat the eggs and may destroy up to 50 per cent of the eggs in some areas. Others, like bee flies and blister beetles, deposit their eggs in the soil near grasshopper eggs. When the larvae of these egg predators hatch, they locate the egg pods and feed upon the eggs. When bee flies and blister beetles are abundant, they may destroy up to 80 per cent of eggs in a localized area.

Predators of nymphs and adults - Spiders, some wasps and many birds feed on grasshoppers and consume them in large numbers. However, their effect upon the total grasshopper population is not fully known.

Parasites - Egg parasites - A few other insects, such as the tiny wasps of the genus **Scelio,** parasitize eggs just after they have been laid. The young parasitic larvae complete their development within the eggs in time to emerge as adults and parasitize the eggs of the next generation of grasshoppers. They may destroy from 5-50 per cent of the egg populations.

Parasites of nymphs and adults - This group contains a large number of natural enemies including flesh flies, tachinid flies, muscid flies and tangled-veined flies.

Most of the fly larvae either burrow into the grasshopper when they contact it on the ground or are deposited on or into the grasshopper's body by the female fly. The fly maggot then feeds inside the grasshopper and eventually kills it as it leaves the body. This group of insects may parasitize up to 60 per cent of the nymphs and adults.

Threadworms may be found coiled inside grasshoppers. They attack grasshoppers if the young worms encounter a grasshopper or if grasshoppers eat threadworm eggs. Threadworms overwinter in soil and lay their eggs on the soil or on vegetation.

Pathogens - The fungus, **Entomophthora grylli,** can be effective in controlling grasshoppers under warm, humid conditions. This fungus may occasionally reach epidemic proportions. The disease leaves the corpses of its victims clinging to the stems of plants.

The microsporidian parasite, **Nosema locustae,** has also been shown to be an effective enemy of grasshoppers. A grasshopper becomes infected if it eats infected vegetation or a diseased grasshopper.

A grasshopper population infected with this organism may be reduced by as much as 60 per cent in one year. It also affects grasshopper populations by reducing the number of eggs laid and by restricting the movement of individuals. Perhaps this organism's greatest potential as a biological control agent, however, is for reducing food consumption.

Since most of the natural enemies of grasshoppers are already widespread it is unlikely that they could be used to prevent grasshopper outbreaks over extensive areas. Nevertheless, natural enemies do play an important role in controlling localized grasshopper infestations and are important in hastening the decline of grasshopper outbreaks.

Poultry - During the depression, some farmers successfully used turkeys to control grasshoppers. In years when grasshoppers were plentiful, the turkeys were simply released into fields. This resulted in a secondary benefit: the turkeys required little supplemental food from the farmer since grasshoppers provided them with a plentiful high quality protein diet.

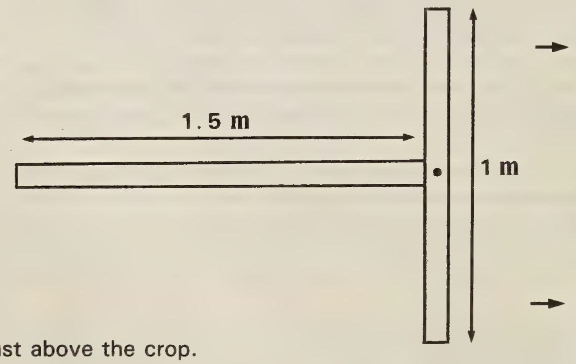
Other birds - Gulls, hawks, crows, meadowlarks, small field birds, crowned larks, lark buntings, desert horned larks, shrikes, curlews, kildeer, partridges and cranes are all noted as predators of grasshoppers. Many birds scratch up the egg cases, and have been credited with clearing from 5 to 150 acres of grasshopper pods. Birds, especially gulls and meadowlarks, are credited with stopping some infestations in the early part of the century. This is more likely to happen if a habitat providing food and refuge for the birds is available. Farm habitat can be made more attractive to birds and so encourage predation of insect pests by birds. This is a cheap control measure.

Vertebrates other than birds - Most animals are opportunists - they will eat what is nourishing and available to them. Mice, shrews, gophers and badgers all eat grasshoppers and their egg pods. Coyotes, skunks, lizards, snakes, toads, bobcats and kit foxes eat nymphs and adults.

Economic importance - Clear-winged grasshopper has been on average, the most economically important species of grasshopper in Canada, although over the years its importance relative to other species has changed gradually. The first record from the Prairie Provinces was from Saskatchewan in 1800. Clear-winged grasshoppers did not become abundant, however, until about 1900 when road-building, drainage and cultivation in southern Manitoba created favorable breeding sites and greatly increased the abundance of suitable food plants. In recent years there has been a marked lessening in the intensities of outbreaks in Manitoba. Perhaps this is related to changing agricultural practices which have reduced populations of certain grasses.

Damage Description - Damage to cereal crops is generally concentrated near field margins, whereas in grasslands the damage is more evenly distributed. Feeding damage to cereals includes leaf stripping and is heaviest when stems are severed just below the seed heads of maturing and mature crops. Under conditions where grasshopper numbers are extremely high and natural plant hosts in short supply, grasshoppers will consume or attempt to consume any plants or plant products which they come upon during their migrations in search of food.

Sampling and monitoring methods - Walk through the infested area and estimate the number of grasshoppers per square metre as they jump in front of you. A sampling 'T' as depicted below consists of a metre long measuring stick, carried by means of a handle so that a square metre can be visualized at crop height. This will improve your estimate.



Walk carrying the T just above the crop.

Late summer-fall surveys of grasshopper adults have been carried out by agricultural fieldmen in Alberta since 1932.

Spring surveys of grasshopper eggs and of egg hatch are conducted in years of expected high grasshopper numbers. In this way, improved estimates are obtained for time of hatch, population density and the effects of predators and parasites.

Economic threshold

	Number of grasshoppers/m²	
	Field	Roadside
Control not usually required	0-6	0-12
Control may be required	7-12	13-24
Control required	13+	25+

Management strategy

Effects of weather - Population size is primarily determined by weather conditions. Outbreaks are usually preceded by two-three years with hot, dry summers and open falls. Dry weather increases the probability of egg survival, hastens spring hatch, and promotes nymphal development and adult feeding. Open falls allow grasshoppers more time to feed and lay eggs. Cool, wet weather increases egg mortality by promoting fungal diseases, retards nymphal development, reduces the numbers of eggs laid by delaying sexual maturity, and reduces grasshopper activity of all stages.

Cultural

Tillage - Cultivation of the soil is probably the most effective cultural practice available to farmers for the reduction of grasshopper populations. Tillage controls grasshoppers primarily by eliminating the green plants on which grasshoppers feed.

It is of little value to undertake tillage for the sole purpose of physically destroying grasshopper eggs or exposing them so that they dry out or are eaten by birds and other insects. Excessive tillage may even be harmful if it increases the risk of soil erosion.

Fall tillage to eliminate weeds from summerfallow fields during late summer and early fall will discourage female grasshoppers from depositing their eggs in these fields. Grasshoppers seldom lay eggs in clean summerfallow even when it has a heavy covering of trash. Similarly, thorough cultivation of fields immediately after harvest will help discourage grasshoppers from laying all their eggs within the field.

It is advisable to complete early spring tillage before grasshoppers have hatched in order to eliminate all green growth on stubble fields which are to be summerfallowed. If no food is available for them to eat when they hatch, young grasshoppers will starve to death because they are unable to move long distances to locate other food sources. Early tillage will also give good weed control and conserve moisture at no extra cost.

Trap strips - If grasshoppers are present when tillage operations begin, it will probably be impossible to achieve adequate control by simply eliminating all green plant materials in a field. Once grasshoppers have fed and developed to the second stage of growth (second instar) in a field, they usually are mobile enough to move to adjacent crops when their food supply becomes exhausted. In these fields trap strips should be used to collect grasshoppers into a relatively small area. Then it will be possible to control them quickly and economically using a minimum amount of insecticide.

To make strips, cultivate a black guard strip 10 m wide around the outside of a field. Leave an unworked green strip at least 10 m wide before resuming cultivation. Repeat the process as often as necessary to produce additional trap strips. All green vegetation must be eliminated between the trap strips if they are to be effective. The black guard strip will ensure that grasshoppers promptly move into the trap strips to feed.

The effectiveness of trap strips can be improved considerably by seeding them to wheat, barley or oats several weeks before tillage begins. The trap strip should have adequate vegetation to feed even the largest of grasshopper populations for three to five days.

Migration of young grasshoppers from the cultivated guard strips to the trap strips may take several days. Once the migration is complete, the trap strips and a 10 m strip of adjacent crop should be treated with insecticide. Apply the highest recommended rate of insecticide to ensure adequate control.

Before cultivating the trap strips, allow three days to assess the effectiveness of the insecticide. If adequate control is not achieved after three days, treat the trap strip again. When grasshoppers have been eliminated from the trap strip, it should be possible to complete tillage without fear of displacing large numbers of grasshoppers into adjacent crops.

If summerfallow is not properly managed, it may be a major source of grasshopper invasion. Many of the reported cases of growers having to apply insecticides six or seven times to a field border are a direct consequence of improper grasshopper control on summerfallow fields.

Early seeding - Crops should be seeded as early as possible. Older plants that are growing vigorously can withstand more grasshopper feeding than younger plants that are not well established. Although early seeding may not totally prevent crop damage, it will reduce crop damage and allow more time for the farmer to obtain and apply insecticides. Also, early seeded crops mature early and migrating grasshoppers are not as likely to be attracted to them.

Crop rotation - Whenever possible, avoid seeding cereals on stubble fields heavily infested with grasshoppers. Cereals should be seeded only on stubble fields where soil moisture is adequate and where one or more applications of an insecticide over the entire field is economical.

Roadside vegetation management - Certain of our common roadside weeds, such as stinkweed, alfalfa and dandelion, are nutritious food plants for nymphs and adults. Such plants promote high survival and egg laying. Western wheat grass on the other hand, is one of the poorest foodplants.

GRASSHOPPER — Migratory
Melanoplus sanguinipes (Fabricius)

Host plants - The migratory grasshopper is one of the most destructive pests in western Canada, particularly on the Prairies where outbreaks can lead to costly losses for the grain grower. The species attacks both field and garden crops, especially cereals, tomato, celery, onion and carrot.

Overwintering - Females lay pods containing about 25 eggs in stubble and wheat fields, between clumps of grass or in other patches of dry soil during August and September. The eggs of this species and others in the genus **Melanoplus** can complete up to 85 per cent of their embryonic development prior to overwintering.

Spring appearance - Eggs hatch between early May and mid-July, although this may be earlier or later depending upon temperature and moisture conditions in both spring and the preceding fall. Watch for signs of hatching in stubble fields and along roadsides and pastures where adults were seen congregating in August and September.

Number of generations - As with all of Alberta's pest grasshopper species, migratory grasshoppers have one generation per year.

Natural enemies - See clear-winged grasshopper

Economic importance - Migratory grasshopper is normally the most numerous pest grasshopper species in Western Canada where it is often injurious to cereals. In an outbreak in Saskatchewan in 1940 there was nearly complete crop destruction at the center of the outbreak and crops were heavily damaged in a 600 mile radius.

For information on the following sections, see clear-winged grasshopper.

GRASSHOPPER — Packard's
Melanoplus packardii (Scudder)

Host plants - Packard's grasshopper prefers herbs to grasses and hence causes little damage to rangeland, but it does cause damage to field and garden crops and to legume pastures. They feed on leaves, stems and flowers of many plants. Cereals and alfalfa are heavily attacked.

Overwintering - Females lay one to several egg pods in grain fields or along roadsides, mostly in August and September. Each pod contains about 20 eggs. The egg stage overwinters.

Spring appearance - Eggs hatch between early May and mid July, the dates of hatching depending upon temperature and moisture conditions. Nymphs, which are green or fawn colored, molt through five nymphal instars before becoming adult in three to seven weeks. In cooler seasons development is slowed and nymphs persist into the fall.

Number of generations - There is one generation per year.

Natural enemies - See clear-winged grasshopper.

Economic importance - Packard's grasshopper is found in the four western provinces. It has been described as being on occasion the second most important species of grasshopper in Alberta, and the third most important in Saskatchewan where it has comprised 12 per cent of the total grasshopper population. It tends to be associated with the migratory grasshopper, **M. sanguinipes**, and to occur especially in stubble fields and in light soil areas. It has caused considerable damage to fall rye and winter wheat.

For information on the following sections, see clear-winged grasshopper.

GRASSHOPPER — Two-Striped
Melanoplus bivittatus (Say)

Host plants - Two-striped grasshoppers feed on both grasses and broadleaved plants, the broad-leaved plants being necessary for maximum growth. They prefer the lush growth found around edges of streams, marshes and cultivated fields. Hosts include weeds, most crops, especially alfalfa and vegetables, and occasionally trees and shrubs. They were first noted in large numbers in 1932 after broadleaved weeds became common on the Prairies.

Overwintering - This species overwinters as eggs. Drift ridges of soil in abandoned fields that suffered severe wind erosion have been favored egg laying sites. Others have noted egg laying in heavier textured soils along roadsides, closely cropped pastures, fence rows, ditch banks, prairie sod and field margins, but not in cropped fields.

Air temperature must be above 20°C and soil moisture between 10 and 20 per cent for egg laying to occur. Forty to 100 eggs are laid per pod; only two or three pods are laid by each female during August and September.

Spring appearance - First instar nymphs appear in late May to early June.

Number of generations - There is one generation per year.

Natural enemies - The two-striped grasshopper has a greater number of natural enemies of the egg stage than have the clear-winged or migratory grasshoppers. The nymphs and adults are attacked by at least twelve species of insect parasites, two mermithid nematode species, three microbial pathogens and by various birds, small mammals and parasitic mites. Insect parasites are most abundant two or three years after an outbreak. There are various records of heavy mortality from fungus disease to which, in Alberta at least, the two-striped grasshopper seems particularly susceptible. Red mites have infested up to 100 per cent of a population, however, about 8 per cent is a more normal figure. Their effect on the hoppers has not been studied.

Damage - See clear-winged grasshopper.

Management strategy - See clear-winged grasshopper.

GREENBUG

Schizaphis graminum (Rondani)

Host plants - The greenbug feeds on cereals and forage grasses. Late-sown oats, barley, fall rye and wheat are usually susceptible when this aphid is abundant, although in one year the greatest injury was to early seeded fields of fall planted cereals. Timothy grown for forage is said to be most susceptible because of succulent growth that appears after cutting.

Insect Control

Overwintering and spring appearance - The species is normally unable to survive the winter in Canada. However, eggs laid in the fall on dead foliage of winter wheat and fall rye are said to have survived the winter. Fortunately they hatched before there was any seedling growth on which the aphids could become established.

Infestations are initiated mainly by flying aphids that are carried into Canada on southerly winds. The species passes the winter on fall planted wheat and volunteer grains in Oklahoma and Texas. It migrates north in the spring. It passes through several generations while migrating, and the numbers that eventually reach Canada are presumably influenced by whether migrating individuals find suitable food plants and southerly winds at the right times. In 1986, infestations in southern Alberta were not noted until early July.

Number of generations - The greenbug produces many generations each growing season. The number of generations that can be produced in Alberta presumably depends on the time of initial infestation, crop condition, and temperature.

Predators - Lady beetles (lady bugs), lacewings, big-eyed bugs.

Parasites - Parasitic wasps.

Economic importance - The greenbug, an introduced species, has been recorded in the Prairie Provinces since 1907 but is not normally a problem since it does not overwinter in Alberta. Heavy migration and outbreaks do occur, however, and in the 1930s and in 1986, large areas were infested. This species of aphid injects a toxin into plants while feeding.

The toxin causes brown spotting at feeding sites and yellowing of the plant. Plants are set back from their normal maturity date. The aphid can carry barley yellow dwarf virus and maize dwarf mosaic virus.

Damage Description - The condition of host plants may influence infestations: in one instance damage to late seeded barley and oats was highest in low lying land that had been flooded earlier. In another instance, serious outbreaks were attributed to the coincidence of aphid flight with a time when late crops were at a succulent stage of development. Late seeded crops are more susceptible because they are less able to withstand attack, have more succulent growth which is attractive to aphids, and are less likely to produce a crop should plants recover.

Damage is caused primarily by the toxin which is injected into the plant. When the aphids feed, colonies of this aphid are found on the lower parts of the plant; necrosis (browning) of lower leaves was noted throughout infested fields during the 1986 outbreak. From a distance, however, fields took on a yellow appearance which was evident, on close inspection, in the top growth. In many barley fields, the yellowing problem was likely attributed to severe scald and net blotch prevalent in 1986.

Economic threshold - More than 30 aphids per stem warrants immediate control action (i.e. chemical control) although abundant predators and parasites should enable greater populations to be tolerated.

Management strategy

Effects of weather - The species has been abundant in hot dry weather. Cool weather is believed to have prevented it from increasing. Rain can wash migrating aphids out of the air.

Biological - Predators, especially lady beetles, often have been important in preventing population increases and in controlling outbreaks.

LYGUS BUGS

Lygus (spp.)

Host plants - Lygus bugs feed on a wide variety of crop plants but alfalfa and canola are preferred. Weed hosts include flixweed, kochia, lamb's quarters, mustard, Russian knapweed and Russian thistle.

Overwintering and spring appearance - Lygus bugs overwinter as adults under debris, litter, or plant cover along fencelines, ditchbanks, hedgerows and wooded areas. In the spring, adults become active and feed on early growing plants, mate and migrate to crops when they become suitable for feeding and egg laying. This may be as early as mid-May in the southern prairies to mid-June in the Peace River areas.

Number of generations - Lygus bugs have two or three generations per year.

Predators - Damsel bugs, ladybird beetles, green lacewings, pirate bugs, big-eyed bugs.

Parasites - This pest is attacked by an insect parasite that also attacks four other species of forage crop plant bugs, and by a nematode.

Economic importance - Lygus bugs are general feeders and are found on many herbaceous plants. They are most damaging to alfalfa grown for seed but are also active feeders on canola. The tarnished plant bug, **Lygus lineolaris,** feeds on a wide variety of forage crops, vegetables, fruits and flowers and is the most economically important lygus bug on the prairies. Two other Lygus species, **L. borealis** and **L. elisus,** are also pests of canola and alfalfa seed production.

Damage Description - In northern parts of the Prairie Provinces and British Columbia these bugs often have prevented alfalfa from blossoming by causing bud blasting. When alfalfa is attacked the buds turn white and fail to develop, the flowers fall without forming pods, the pods fall off before they are mature, or the seeds are discolored or shrunken. In one instance 10 to 25 per cent of blossoms were destroyed and in another, lygus damaged seed averaged 25 per cent of yield. One heavy infestation in alfalfa was caused by bugs that migrated from nearby snowberry. On alfalfa, eggs are laid in upper parts of the plants. Populations tend to build up quickly where alfalfa is grown under irrigation and when the weather is damp but tend to remain low when the weather is hot and dry. Wet weather, however, may cause a lack of seed setting that may obscure any damage that the bugs may cause. Cool weather reduces feeding activity.

Lygus bugs have piercing-sucking mouth parts and physically damage plants by puncturing tissues and sucking the plant juices. Plants also react to the toxic saliva that the insects inject when they feed. Lygus bug infestations can cause alfalfa to have short stem internodes, excessive branching and small, distorted leaves.

Lygus adults also feed on the base of canola buds and flowers, causing blasting damage quite similar to that of alfalfa. Buds that are attacked appear shrunken and bleached white. When pods develop in late July and early August, older nymphs and adults feed on the developing seeds by puncturing pods and sucking out the seeds' contents. Damaged seed appears dark brown and shrivelled. A droplet of fluid may be seen on the exterior of the pod at the puncture site.

Sampling methods - Sweep net samples of the top 20-25 cm of the crop.

Economic threshold - In alfalfa grown for seed: 2-3 adults or five nymphs/sweep during bud and bloom; four adults/sweep after bloom.

Management strategy

Biological - Controls in alfalfa grown for hay are not necessary, as natural predators and parasites, along with mowing and harvesting, reduce lygus bug populations.

Overwintering mortality is believed to be high, with 40 to 60 per cent survival under the most favorable conditions. Some figures indicate that the population of nymphs in August may be about 30 to 80 times the size of the population of overwintered adults in the spring, and that the population of adults before hibernation may be up to 50 times the size of the overwintered population. A larger than usual number of overwintering adults and unusually heavy damage to tobacco were both related to dry weather. A rapid increase was attributed to lush plant growth caused by high rainfall. Scarcities were attributed to cold wet weather.

Cultural - Tarnished plant bug, **Lygus lineolaris,** can be controlled in ornamental plantings by removal of weeds and keeping lawns or grassy areas mowed to eliminate breeding sites.

PALE WESTERN CUTWORM
Agrotis orthogonia (Morrison)

Host plants - Pale western cutworm is important as a pest of wheat but can also be damaging to rye, oats, barley, mustard and flax. It prefers wheat to barley and will also feed on sugar beets, legumes and on thistles and various other weeds.

Overwintering - Eggs are laid just below the surface in loose, friable soil, in cracks in hard packed soil, and in stubble fields. Females lay a total of 150 to 400 eggs during August and September before frost kills the adults. Egg laying occurs in late afternoon and early evening.

Spring appearance - Eggs hatch between the end of March and the beginning of May. There is sometimes abnormal hatching in the fall if the weather is cool. The newly hatched larva can withstand starvation for up to several weeks. Freezing temperatures are not a serious hazard to survival and hatching of the egg. The larva feeds on growing leaves below the soil surface.

Number of generations - There is one generation annually.

Natural enemies - Frequent rainfall reduces populations by saturating the soil and forcing larvae to the surface where they are exposed to attack by predators, including birds, beetles and ambush bugs. On the surface they feed on the upper parts of plants where their tachinid fly parasites lay eggs. The tachinid parasites can be important. Excessive moisture apparently has no significant effect in reducing cutworm numbers in the absence of parasites and predators. Parasitism is low and the effects of predatory birds and insects are negligible in dry weather.

Damage Description - The first sign of injury is the appearance of small holes in the leaves. These holes are cut while a portion of the leaf is still underground. As growth continues, this leaf area emerges and the holes can be noticed. Cutworms at this time are very small and difficult to find. As the larvae increase in size, they move along the row, cutting off leaves and often entire plants. Their behavior is similar to that of red-backed cutworms. Injury from older cutworms may be distinguished from drought by pulling up the plant. If only the plant stems without the roots are removed, cutworm injury is indicated. If the entire plant can be easily pulled, drought is indicated. Major damage is stem weakening caused by older larvae chewing the stems just below soil level, making the crop susceptible to wind damage. Damage ranges from complete destruction of individual fields to partial destruction over thousands of acres. Outbreaks have occurred in the Prairie Provinces with no apparent pattern since 1911.

Sampling and monitoring methods - Since 1978 pale western cutworm moths have been monitored using pheromone traps in southern Alberta. In 1985, a province-wide pheromone monitoring system was established for this and other cutworm species.

Sampling for numbers of larvae in a field is accomplished as for other subterranean cutworm species. Mark an area of soil one-half metre square running with the rows. During the day, larvae should be found within the top 5-7 cm of soil. Count the number of larvae within the quarter square metre. Repeat the process in different areas of the field. Calculate an average number of larvae per square metre for your field.

Economic threshold - Infestation levels of 10 cutworms per square metre in winter wheat or five per square metre in spring cereals, generally warrant spraying. If there are more, or if obvious thinning of the stand is occurring, immediate control is necessary. Infestations may be patchy within fields, and evident especially on high areas and hill tops. Examine the edges of bare patches to determine cause of uneven plant distribution.

Management strategy

Effects of weather - There are many records of infestations having been halted, reduced or prevented by wet weather. Frequent rains also reduce damage by promoting plant growth. Conversely, damage can be severe when the spring is dry. Less than 10 wet days in May and June produces an increase in cutworm populations. Dryness can delay egg laying and under drought conditions larvae can be killed by desiccation, which may explain why there can be less damage in a dry than a moist soil. Usually a spring with 12 or more wet days will reduce the cutworm population to a point where two or three dry springs are needed to develop a damaging population. A wet day is one on which the soil is too wet to use a disk-harrow regardless of whether it is raining.

Cultural - Farming operations can influence cutworm populations. Any disturbance to the soil, for example, by harvesting, cultivating or pasturing during the oviposition period (August and early September), tends to produce an infestation in the following year because it makes the soil surface suitable for egg laying. A crust on the soil of summerfallow fields left undisturbed during August and September prevents the occurrence of infestation in the following year.

Tillage for weed control - In May, a delay of five days or more between cultivation and seeding can terminate an infestation. The larvae will die if either they feed after they hatch and then are deprived of food for several days, or if they cannot feed at all for 10 to 14 days (less if the weather is warm and sunny).

Timing of this first tillage operation is important. The field should be cultivated when the vegetation is between one and two inches above the ground surface. If the land is cultivated too early, before the cutworms have started to feed, they will simply remain inactive and cannot be starved out.

When trying to judge when to cultivate the land to destroy weed growth, stinkweed should not be used as an indicator plant. Stinkweed is usually the first plant to appear in the spring. Cutworms do not feed on this plant, however, and will not become active until later.

Although the starvation control method is effective if done properly, it has a serious disadvantage in that it may delay seeding until it is too late to sow wheat. Barley, flax, or a greenfeed crop may have to be sown in place of wheat. Even if wheat can be sown, however, the shorter growing season may reduce yield. In view of these disadvantages this control method should only be used on fields disturbed during a heavy egg laying period the previous year.

Crop rotation

Keeping in mind that fields should not be disturbed between August 1 and mid September in order to discourage cutworm egg laying, you may find the following or a similar rotation useful:

1st year: Summerfallow seeded to fall rye before August 1, pastured if desired after September 15.
2nd year: Harvest rye before August 15.
3rd year: Oats or barley, seeded as a nurse crop to sweet-clover and cut for hay or greenfeed about July 15, can be pastured after September 15.
4th year: Cut sweet-clover for hay in late July or for seed after September 15.
5th year: Plant spring wheat, followed by a year of summerfallow.

Biological - Parasites and predators are unlikely to be effective in dry weather.

PEA APHID
Acyrthosiphon pisum (Harris)

Host Plants - Field peas and alfalfa in the irrigated areas of southern Alberta may be severely damaged by the pea aphid, **Acyrthosiphon pisum.** This insect, which also feeds on sweet-clover, trefoil, vetch, sweet peas, broad beans, and several varieties of clover, is found in Alberta wherever peas and forage legumes are grown.

Overwintering - Pea aphids overwinter as eggs on leaves and stems of various perennial legumes.

Spring appearance - In spring, when overwintering plants resume growth, a small light green wingless female hatches from each egg. These aphids, females called "stem mothers", reproduce without mating. They feed on the growing plants and give birth to other female young. Some aphids of the second and third generations become winged and migrate to peas and other acceptable host plants. Here they feed and produce wingless females that give rise to other generations of both winged and wingless females.

Number of generations - Generation time and numbers of offspring produced are factors greatly influenced in aphids (and insects generally) by temperature and food quality. Accordingly, aphids develop from birth to maturity in 5 to 50 days. All pea aphids are female throughout spring and summer; a summer female can produce from 50 to 150 young during her life.

Predators - Include syrphid fly larvae,and adults and larvae of ladybugs, lacewings, damsel bugs, pirate bugs, lygus bugs and predaceous plant bugs.

Parasites - Pea aphids are parasitized by tiny wasps which lay their eggs inside the aphids, one egg per host. The wasp larvae eventually kill their hosts.

Damage Description - This aphid generally infests the growing tips of plants. Both adults and young pierce plant tissues and suck juice from leaves, petioles, stems, and flower buds.

Most healthy plants can withstand moderate infestations without showing damage. However, large populations cause alfalfa plants to become stunted and wilted. Upper leaves become light green, and lower ones become yellow and die. Yield and quality of hay may be greatly reduced. From a distance, the affected area of an alfalfa field appears brownish, and close examination will reveal shed aphid skins on the ground beneath the plants. Where growth of alfalfa is retarded, weeds may take over and crowd out the alfalfa. Large numbers of aphids are a nuisance during haying, cubing and dehydration.

This aphid transmits viruses such as alfalfa mosaic, alsike clover mosaic, bean yellow mosaic, pea enation mosaic, pea mosaic, pea streak, and red clover vein mosaic. However, these diseases have been of minor importance in Canada.

Sampling and monitoring methods - The simplest method of assessing aphid densities in alfalfa is with a sweep net: a 38 cm diameter fine net bag with a 1 m handle is commonly used. Sweep the net in a 180° arc through the tops of the plants five times (five sweeps). Count the number of aphids collected (or estimate their number if numerous) to obtain an average number per sweep. Repeat the process in four different spots in the field. In field peas, count the aphids on at least twenty, 20-cm stem tips taken from four different spots in the field.

Economic threshold - The economic threshold varies with yield expectation, commodity price and cost of control. According to Dr. B. Schaber (Agriculture Canada, Lethbridge), in 1986, 150-200 pea aphids per sweep in alfalfa justified control. Dr. R. Lamb (Agriculture Canada, Winnipeg), reports that the density of pea aphids in field peas should be assessed when the crop begins to flower. If the economic threshold of 9-12 aphids per sweep or 2-3 per tip is exceeded at this time, a single application of insecticide when 50 per cent of the plants have produced some young pods will protect the crop against yield loss and the application will be cost-effective.

Management strategy

Effects of weather - Weather favorable for rapid growth of alfalfa greatly reduces the possibility of aphid damage. Aphid infestations may be reduced by very hot weather and retarded by cold weather. Heavy rains may dislodge and kill aphids.

Resistant and susceptible varieties - Several varieties of peas, such as Pride and Onward, are not severely damaged by aphids.

In studies of pea aphids in Manitoba pea fields from 1980 to 1983, it was found that most fields had aphid densities that exceeded the economic threshold. Aphids reached higher densities on the cultivar Trapper than on Century, indicating that control is more likely to be required in fields of Trapper.

Fababeans were severely damaged by pea aphids in greenhouse tests. In the field, however, this crop is planted early, becomes established and seems to be past the susceptible stage when aphids migrate from perennial crops.

Insect Control

Harvesting - Cutting alfalfa hay in the early bloom stage, then removing the hay from the field quickly and immediatly irrigating, reduces aphid damage to new plant growth. This allows the crop to become well established before the aphid population again becomes large.

Biological - Predators and parasites attack the pea aphid and help to keep it under control. Usually they become abundant only when the aphid is abundant. The predators are mainly adults and larvae of damsel bugs, pirate bugs, ladybird beetles and lacewings, and larvae of syrphid flies. The parasites are the larvae of tiny wasps which live in the aphids and eventually kill them. When aphids are unusually abundant, spiders and birds also eat them.

A fungus disease may sometimes eliminate infestations of aphids in warm moist weather.

PRAIRIE GRAIN WIREWORM

Ctenicera aeripennis destructor (Brown)

Host plants - The prairie grain wireworm is considered the most destructive wireworm pest of grain in western Canada. It prefers grasses, both annual and perennial. It also attacks potato, sugar beet, corn, lettuce, sunflower, canola and seed onions.

Overwintering - Wireworms (the larval stage) live for several years in the soil and are quite resistant to adverse conditions. Those larvae which survive their first winter can go for at least two years without any food other than humus. The wireworm stage lasts anywhere from 4 to 11 years. They hibernate from 5 to 25 cm in the soil. Older larvae are commonly found feeding to a depth of 15 cm in the topsoil. When full grown, usually in July, the larvae pupate about 5 to 10 cm deep in the soil. Pupation lasts for less than a month, however, adults do not emerge until the following spring.

Spring appearance - Wireworm adults, called click beetles, emerge in April and early May from the soil in which they overwintered. They become active when the air temperature is above 10 °C, mate and then seek egg laying sites. From late May through June individual females will deposit from 200 to 400 eggs in loose soil, or under lumps of soil. Depending on the moisture, temperature and firmness of the soil, eggs are laid anywhere from just below the soil surface to 15 cm deep. After three to seven weeks, young wireworms hatch and begin to feed on living roots or germinating seeds of cereals or grasses. If no food is found within one to four weeks of hatching, the larvae will die.

Number of generations - The generation time (4 to 11 years) varies according to the quality and availability of food. Wireworms in all stages of growth are likely to be found together in an infested field.

Parasites - Parasitic nematodes attack the larvae.

Pathogens - Larval mortality caused by bacterial diseases is especially high in soils of high moisture content.

Economic importance - In Alberta, damage to wheat crops ranges from 1 to 50 per cent annually. Damage to other noncereal crops varies from farm to farm. Over 80 species of wireworms have been found in Alberta but only the prairie grain wireworm is of major economic importance.

Damage - The larvae feed upon germinating seeds or young seedlings, shredding the stems but seldom cutting them off. The central leaves die but outer plant leaves often remain green for some time. Damaged plants soon wilt and die, resulting in thin stands. Thinning can also be caused by poor seed and dry conditions, therefore many wireworm infestations are passed off as poor seed or poor germination. Wireworms do most of their damage in early spring when they are near the soil surface. During summer months, larvae move deeper into the soil where it is cooler and where moisture supplies are plentiful. Wireworms do not ingest solid plant material, but chew tissues, regurgitate fluids containing enzymes, and then imbibe the juices and plant products made soluble by the enzymes.

Potato seed pieces are seldom damaged to a point where poor stands result. However, new tubers can be damaged severely. Tunelling allows disease organisms to enter and damaged tubers are usually less marketable.

Damage is generally higher in silty, medium textured, well drained soils and in soils cultivated for at least 12 years. Damage is less likely in heavy or very light soils. Crops grown in newly broken sod can suffer great losses for one to two years, then the damage decreases rapidly only to gradually increase in succeeding years if no wireworm control measures are applied.

Sampling and monitoring - Whole potatoes buried in marked locations in a field in the spring or from early to mid-August will indicate whether wireworms are present. Bury the potatoes 10 to 15 cm deep for a couple of weeks, then dig them up and examine them for wireworm tunnels. Monitor your fields each year.

To sample for numbers of larvae, sieve the soil through a screen. Mark out areas one-half metre by one-half metre and sieve the soil to a depth of 15 cm. Repeat in different areas of the field to determine an average number of larvae per square metre.

Economic threshold - None established. Treating seed for two consecutive years after breaking sod will normally reduce the problem to an uneconomic level.

Management strategy

Effects of weather - Larval activity is governed by temperature and moisture conditions. Cool wet weather forces wireworms closer to the surface whereas dry hot weather forces them deeper into the soil. Also, cool weather restricts adult activity and lengthens the egg laying period. Eggs laid near the soil surface or in compact soil are subject to high mortality when rapid fluctuations in moisture and temperature occur. Mortality is estimated at from 92 to 98 per cent in eggs and young wireworms. Most wireworm mortality occurs during the first two weeks of larval life.

Crop rotation - Crop rotation and other cultural practices usually prevent wireworms from becoming a major problem in sugar beet fields. Because sugar beets are normally grown in a four year rotation in Alberta, crops less susceptible to wireworm attack can be grown on infested fields so populations will not build up. Root and row crops, such as potatoes, corn, onions or beans should not be grown in rotation where wireworms have been a problem. Wireworms can also be present when sugar beets are grown on land previously uncultivated or planted to grass or pasture. Deep ploughing in fall and frequent cultivation in early summer is suggested when wireworms are known to be present in these fallowed fields.

Shallow cultivation - The long life and underground habit of wireworms makes them very hard to control. The most vulnerable stage of the wireworm is the egg and early larval stage. Only two to eight per cent of eggs and young wireworms survive. Newly hatched wireworms must feed within four weeks. Thus, any fallowing or starvation control should be done in early spring when the eggs hatch. Shallow cultivation in early spring can expose eggs and injure larvae. Also, thorough cultivation of summerfallow during the latter half of July can destroy pupae as well as larvae. Use a rod weeder and disturb only the upper soil layer. These cultivations should be followed by some planting, however.

Summerfallowing - Summerfallowing for wireworm control is not recommended, since it has almost no effect on mature larvae which can survive for two years on soil humus alone. In fact, wireworm damage is more severe after fallow. If early spring cultivation is used to starve and injure young larvae and eggs, then it is best to follow this with the seeding of a resistant crop.

If summerfallow must be part of the rotation, starve newly hatched wireworms by destroying all green growth during June and July. Work summerfallow as shallow as possible for weed control. Seed shallow and pack the seedbed to induce quick germination, and avoid very early or very late seeding.

Shallow cultivation or seeding combined with soil packing - Packing behind the seed drill is recommended for reducing damage to grain in wireworm infested land. Wireworms are very poor travellers. Some remain in the larval stage for nine or ten years, during which time they travel only a few yards. By firming the soil the wireworm is further impeded. Use of a press drill is recommended for best results. If a press drill is not used, a packer, hitched behind the seeder in such a way that all wheels of the packer "follow" the drills of the seeder, may be used. Thus, the seed row is packed firmly, making wireworm locomotion so difficult that most of the worms will seek their food in the looser soil between the seed rows. If the packers do not follow the seed rows they will tend to leave them loose while firming the intervening strips. This may encourage the worms to follow the seed rows and cause heavy damage.

Farmers should restrict tillage operations to the upper 5 to 8 cm of the soil in order to maintain a compact soil beneath the tilled layer.

Adult click beetles are also affected by a compact sublayer, because they are forced to lay their eggs close to the surface where they can easily dry out, or be discovered by predators.

Seeding practices - Avoid very early or very late seeding. Use methods which speed germination and early growth of the crop to help reduce the impact of wireworm damage. Cultivate prior to spring seeding to give the crop a competitive advantage with weeds and to prepare a good seedbed. On land summerfallowed the year before, the rod weeder will produce a very compact seedbed. On stubble, use the one-way disc,then seed at the proper time. If the soil is moist, seed 10 to 14 days from when drilling was first possible, so that the soil is warm and seeds will grow quickly. If the soil is dry, delay seeding until it rains. As much as 90 to 95 per cent of a crop has been destroyed when seeded into a dry soil compared with 5 to 10 per cent loss when seeded into moist soil. Moisture also helps young seedlings recover from wireworm damage.

Shallow seeding - Seed preferably at a depth of 2 to 5 cm. This speeds up the early growth of plants (as long as moisture is present). Use a drill press or standard drill with press attachment. If not available, use a standard double disc drill. Avoid the use of single-disc drills, and hoe-drills, but if you must use them, use press attachments or follow with a packer.

Increase the seeding rate in fields infested with wireworms, especially when planting wheat. Use as much as an extra bushel per acre, or for a patchy infestation, drill twice. Use good healthy seed. According to researchers a light topping of rotted manure, as with an application of phosphate fertilizers, will help reduce wireworm damage. The phosphorous in the manure probably encourages root development and early maturity. Manure can be applied late in the fallow year or early the next spring, and should be incorporated into the soil.

Do not plant susceptible crops on the same land in two successive years. A crop rotation with resistant varieties and legumes can be useful.

Yellow mustard is used in England to help control wireworms. Buckwheat and flax are not usually damaged. If recommended seeding practices are followed, oats and barley can be planted except in severe infestations. Fall rye and winter wheat are more resistant owing to early vigorous growth in spring. However, a wet autumn preceded by a dry summer and fall has resulted in damage to rye. When planting legumes, seed with a light nurse crop or in a mixture with a grass. Seedlings of sweet-clover and alfalfa but not mature plants can be seriously damaged by wireworms. The seedlings usually escape damage in a mixture.

Take special precautions after breaking sod. If a crop on new land is destroyed, reseed immediately with a resistant crop. This is preferable to leaving the land fallow, since a recurrence of the problem would then be likely.

Biological control

Parasites - A few nematode parasites are now on the market for control of pests that pupate below ground. These include Steinernema feltiae (= **Neoaplectana carpocapsae**), **N. glaseri, Heterorhabditus bacteriophora** and **H. heliothidis.** The best known of these beneficial nematodes is **S. feltiae.**

Nematodes are best known as round-worms or eelworms. The type that infect wireworms and cutworms are extremely minute: one squirt from an oilcan would deliver thousands of the parasites. The nematodes can be mixed with water and sprayed on crops or soil. Water volume can be adjusted for the stage of insects present - more water for greater penetration into soil will give higher infection rates for wireworm larvae, less water for combatting adult wireworms (click beetles) nearer the surface.

Nematodes attack pests by entering their bodies and feeding on bacteria which the nematodes introduce into the pest's body; most hosts die of bacterial infection within a day. As with all crop control agents, nematodes should not be used indiscriminately since they also attack bugs, beetles, ants, wasps, flies and other insects, many of which are beneficial. At present these nematodes are not available for commercial use.

Pathogens - Wireworms are susceptible to bacterial and fungal diseases, and mortality is higher in moist soils.

Predators - Click beetles and their larvae are prey to both birds and small rodents: the adults when laying eggs, the larvae in spring when they are near the surface or when exposed by cultivation. Birds pull them from the soil, and moles and shrews dig for them.

RED-BACKED CUTWORM
Euxoa ochrogaster (Guenee)

Host plants - Red-backed cutworm is primarily a pest of cereals, sugar beet, canola, mustard, and flax in the Prairie Provinces. It has also been recorded feeding on most vegetables, sunflower, sweet-clover, alsike, alfalfa, various tree seedlings and garden flowers.

Overwintering - Red-backed cutworm moths usually lay their eggs just below the soil surface in weedy summerfallow and in weedy patches in crops. The eggs overwinter.

Spring appearance - Eggs usually hatch in April as soil temperatures increase. Larvae begin feeding immediately on any nearby plants and feed for six to eight weeks with most of the damage appearing in June. Larvae generally remain inactive during the day, but at night either come to the surface or move underground in search of food plants.

Number of generations - There is one generation per year.

Parasites - Parasitism must be sufficiently low to permit an infestation of red-backed cutworms to develop. No parasites were found in one severe outbreak and parasite numbers were low in the year preceding an outbreak year. There are also indications that natural enemies are important in suppressing outbreaks and presumably in contributing to the relatively low populations that usually occur in the two or three years following outbreak periods.

Pathogens - Heavy mortality of the larvae from disease has occurred in outbreaks. In British Columbia, this pest is attacked by 18 species of parasitic insects, five species of fungi and three other kinds of microbial pathogens.

Economic importance - An important pest that causes serious damage frequently in the Prairies, red-backed cutworm produces infestations lasting two to four years followed by a minimum of two years of relative scarcity.

Damage Description - Damage by young larvae is characterized by small holes and notches in foliage. Older larvae eat into stems and usually sever them at or just below the soil surface. Infestations in cereal crops are characterized by areas of bare soil that gradually enlarge until anywhere from one to two acres to complete fields. Damage is often patchy, occurring on knolls and light soil areas. These bare areas of exposed soil are often confused with areas of poor germination or moisture stress. The presence of cutworms is indicated by severed dead dried up plants.

Sampling and monitoring methods - Red-backed cutworm moths have been monitored using pheromone traps since 1978 in southern Alberta. In 1985, a province-wide pheromone monitoring system was established for this and other cutworm species.

Sampling for numbers of larvae in a field is accomplished as for other subterranean cutworm species. Mark an area of soil one-half metre square running with the rows. During the day, larvae should be found within the top 5-7 cm of soil. Count the number of larvae within each quarter square metre. Repeat the process in different areas of the field. Calculate an average number of larvae per square metre for your field.

Economic threshold - Not firmly established but three to four cutworms per square metre may justify control. Infestations may be patchy within fields. Examine the edges of bare patches to determine cause of uneven plant distribution.

Management strategy

Effects of weather - Hot, dry Augusts are thought to provide the best conditions for moth feeding at flowers. Egg production and oviposition depends upon the nutrition obtained by flower feeding. The same weather conditions promote the loose, dry soil surfaces necessary for egg laying. Cold weather may be detrimental to larvae and pupae. Wet weather, especially if also warm, promotes fungal diseases in the larvae and promotes plant growth. Warm, dry weather can increase the severity of damage from cutworm attack.

Tillage practices - Crusted soils on summerfallow help prevent egg laying from late July until late September. This is earlier than pale western cutworm (August-September). If weed growth develops in August, it should be destroyed because red-backed cutworm moths usually lay their eggs in weedy summerfallow. They also lay in weedy patches in cereal crops and in fields of canola, peas, alfalfa and sweet-clover. Young cutworm larvae may be starved before spring seeding by allowing volunteer growth to reach 3 to 5 cm, cultivating and then seeding 10 to 14 days later. Cutworms can be located by digging 2 to 3 cm below the soil surface at the edge of the damaged area.

Biological - Since parasite numbers tend to increase after an increase in abundance of the host, very few parasites are found during the first year of an outbreak. However, after two years, parasites are numerous enough to reduce the outbreak and keep cutworm numbers low for at least two years, depending on the conditions mentioned above.

RED TURNIP BEETLE
Entomoscelis americana (Brown)

Host plants - The red turnip beetle is an occasional pest of canola, and mustard crops in Western Canada. It is native to Canada and is most commonly found in the aspen parkland region and Peace River district. The larvae and adults feed on seedling plants in May and June, and the adults feed on mature plants in August and September.

The following plants have been verified as food plants of the larvae: canola, yellow mustard, oriental mustard and brown mustard, dog mustard, shepherd's purse, wild mustard, flixweed, tall hedge mustard, and black mustard. Other common cruciferous weeds which might serve as food plants for the larvae include: ball mustard, tumble mustard, wormseed mustard, gray tansy mustard, green tansy mustard, marsh yellow cress, pepper grass, small flowered prairie rocket, false flax, hoary cress and hare's ear mustard. Neither larvae nor adults feed on stinkweed.

Overwintering - Red turnip beetle overwinters in the egg stage. The eggs hatch in April and early May, shortly after the snow has melted and usually before canola is planted.

Spring appearance - Upon hatching, the black, rough-skinned larvae feed on canola and mustard and on weeds of the mustard family. Larval development normally is completed by the end of May. After development is completed, the larvae enter the soil to pupate.

The adults normally emerge during the first three weeks of June and feed for two to three weeks, usually in the same fields in which the larvae fed. At the end of June, the adults enter the soil to spend the month of July in a resting stage (aestivation). They reappear in August, disperse to new canola and mustard fields, and mate and lay eggs until late October.

Number of generations - There is one generation a year.

Predators - Carabid beetles.

Pathogens - A microsporidian causes disease.

Economic importance - The only damage of economic significance is caused by the adults in June.

Damage Description - In May and June, infestations of both larvae and adults may be found in canola and mustard stubble fields and in other fields containing heavy stands of weeds of the mustard family. If these food plants are all consumed, the larvae and adults may invade nearby fields of seedling canola and mustard. They crawl or walk to new fields and usually are concentrated in a moving front only a few metres wide. Adults have not been seen in flight in June.

Larvae and adults feed on the cotyledons, true leaves, petioles, and stems of seedlings. Depending on seedling size and red turnip beetle abundance, damage will vary from the loss of small portions of cotyledons and true leaves to complete defoliation and death of plants. Small seedlings generally are more readily damaged than large seedlings. If the numbers of red turnip beetles are small, only plants at field edges will be damaged. If beetles are numerous, they gradually move inwards, destroying most of the plants as they go. Larvae generally are not a problem because they normally complete development before the new crops have germinated. Adults may cause sufficient damage in June to warrant control measures.

In August, adults invade canola and mustard fields soon after reemerging and feed on the flowers, pods and stems of plants until harvest. However, the numbers of adults normally are not large enough to significantly reduce seed yield. Control measures, therefore, are not required in August and September to protect yields.

Sampling methods - If large numbers of adults invade newly seeded canola and mustard fields in June, it may be necessary to use chemical insecticides. Fields should be examined carefully to determine the extent of invasion and whether the beetles are causing economic damage. Since they enter fields at the margins by walking and are concentrated in a moving front, it usually is necessary to spray only a small part of each field. If the invasion occurs late in June, the adults likely will not cause economic damage because they will soon enter the summer resting stage.

If the size of the invasion is small or if the beetles are entering only a small area (or both), chemical control may not be necessary.

Economic threshold - None established; however, the following information applies. In assessing damage and potential for economic damage, two factors should be considered: date of invasion, and stage of plant development. Since adults feed for only two or three weeks in June, it is important to remember that they will be damaging rapeseed and canola for less than three weeks. If adults enter fields soon after emergence in early June, they will probably destroy many more plants than if they enter shortly before aestivation in late June, because they have a longer time in which to feed and the plants are smaller. Fields with relatively large plants will require a greater beetle density to cause economic damage than fields with small seedlings.

Management strategy

Cultural - Infestations of red turnip beetle usually originate in canola and mustard stubble fields and other fields containing heavy stands of cruciferous weeds which were not cultivated in the fall and following spring. These infestations can be reduced considerably or prevented completely by using good cultural practices. Cultivation of fields after harvest buries the eggs and thereby kills 75-100 per cent of the next generation because newly hatched larvae cannot reach the soil surface in spring. Destruction of larval food plants by cultivating or herbiciding in April and May will also eliminate most larvae through mechanical injury and many will starve because they can travel only short distances for food. Mechanical injury and desiccation after cultivating in May and June will kill many pupae.

Double seeding along field edges next to fields infested the previous year should reduce the number of sprays required. Since beetles move in mass, one or two passes with a sprayer along the field margin, over and in front of invading insects, will provide control.

Crop rotation to a noncruciferous crop is another way to prevent losses caused by this insect. But take care: adults have caused damage in canola fields situated next to fields where canola was underseeded to fescue the previous year and therefore not cultivated.

SWEET-CLOVER WEEVIL
Sitona cylindricollis (Fahraeus)

Host plants - Sweet-clover is the preferred host but this weevil will feed on alfalfa or cicer milk-vetch if no sweet-clover is available.

Overwintering - The adults overwinter in a sexually immature condition in the stubble and trash of sweet clover fields and in ditches and wastelands where sweet-clover is common.

Spring appearance - Spring populations may number 40 to 170 per square metre (four to 16 per sq ft). The weevils fly readily with the wind when temperature and light intensity are high and humidity is low. They feed at night on the upper leaves and hide when disturbed by light. They hide by day at the bases of plants. Each overwintered female lays several hundred eggs from late May to early August by dropping them indiscriminately on the soil. Larval populations have been estimated to be 50 to 800 times the size of the spring adult population.

Number of generations - There is one generation per year.

Pathogens - A fungus disease that commonly attacks the adults has caused up to 80 per cent mortality.

Predators - The weevils are eaten by toads and grubs.

Economic importance - This is the major insect pest of sweet-clover. It has caused serious damage to sweet-clover throughout Alberta. Damage is mainly to young plants. There are records of almost complete loss of crops in individual fields. Attacks kill seedlings quickly so that the harm caused by this pest is often overlooked or is blamed on poor germination or poor tillage methods. Severe losses can be caused by the combination of heavy attack by this pest and either root rot (which the larvae are suspected of carrying), or dry weather (which retards seed germination and seedling growth). There are wide fluctuations in the relative abundance of this pest in different years. Populations can be high: in one infestation there were more than 2500 larvae and 1000 adults per square metre; in another, almost complete destruction of some fields was caused by an average of 1000 adults per square metre.

Damage Description - Adults chew crescent-shaped, jagged notches in leaves and can completely defoliate plants. They may even eat the outer tissue of stems and green seeds in pods. Damage is most severe in dry years. Seedling crops can be severely thinned or completely destroyed if adults move into a field. Second year stands can be thinned or stunted from the feeding of overwintered adults. Sweet-clover weevils drop from plants when disturbed and so are very difficult to find. The larvae are root feeders. Plant growth does not seem to be affected, however, despite the presence of abundant larvae.

First-year sweet-clover crops planted near or in succession to older crops are especially liable to severe damage, particularly when the second-year crop is cut for hay. Sweet-clover is attacked when growing in grain stubble but apparently not in corn crops or corn stubble. Alfalfa and alsike clover are sometimes harmed after nearby fields of sweet-clover have been harvested. Adults have been found on red clover but apparently not feeding on it.

Sampling methods - Inspect clover seedlings for weevil damage in spring as the seedlings emerge. Weevils may not be seen, but the typical crescent-shaped feeding notches on the leaves are very noticeable. In midsummer and throughout August, inspect first-year clover stands for damage along crop margins. Invading weevils move into these stands only as far as necessary to satisfy their food requirements, so an insecticide application to affected field margins is usually all that is required.

Visually estimate the number of weevils per plant. This must be done carefully because the weevils fall from plants easily and cannot be seen when on the ground. The damage is more obvious than the weevil.

Economic threshold - In a seedling crop growing under slow growth conditions - one weevil for every five seedlings at the cotyledon stage (first leaves prior to true leaves). Under normal growth conditions - one weevil for every three seedlings at the cotyledon stage. In newly emerging second-year crops - 9-12 weevils per plant.

Management strategy

Effects of weather - Weather is important in regulating the size of insect populations. Wet weather seems to be harmful to this pest. Heavy rainfall tends to reduce the effects of attack as it helps plants outgrow the damage. Dew and high humidity inhibit the movement of weevils up the plant at night and probably help spread the fungus disease that commonly attacks the adults. The effects of dry weather are mixed. A population increase was attributed to cold dry weather in May and June; but hot dry weather is said to favor larval survival. The dry weather augments the effects of attack by the weevils. Hot dry weather reduces pest numbers by hardening the soil which prevents larvae from reaching the roots, and probably by killing eggs and newly emerged adults. In one survey a larval population of over 1,700 per square metre before a hot dry period was reduced to only 300 per square metre after. In hot dry weather there is high adult mortality and complete mortality of larvae hatching from eggs laid after July in hot dry soil. Over a four year period in Manitoba, mortality ranged from 95.5 per cent to 99.9 per cent, much of which occurred between fourth instar and adult emergence.

Cultural - Several management practices can reduce losses from sweet-clover weevil. Arrange crop rotations so that clover fields are as far apart as possible. Weevils dispersing in spring and late summer will be less likely to find the first-year crop. Sow clover early (before grain crops) into a firm, moist seedbed and at the recommended shallow depth. This promotes even germination, a fast start, and hardy vigorous seedlings. Cultivate clover fields, silage and hay, as soon as the crop is removed. Cultivation kills the larvae while they are still on the roots.

Blade cultivation following removal of a hay crop has been recommended as a control measure but apparently has no effect on weevil populations. Ploughing to a depth of six inches in October is said to have prevented over 90 per cent of the weevils from emerging from hibernation. Ploughing, disking and cultivating 7 to 12 cm of second-year fields immediately after the hay was harvested is said to have killed 96 per cent or more of the weevils. Tillage of field margins in the fall and planting new fields as far as possible from existing ones are believed to lessen the possibility of severe infestations. Controlling volunteer sweet-clover around fields the year before planting the field to sweet-clover will reduce the possibility of field invasion and damage.

Biological - Next to weather, diseases are most important in population control. The weevils are eaten by toads and grubs. A biological control attempt in Manitoba in 1959 using imported parasites was not successful.

WHEAT STEM SAWFLY
Cephus cinctus (Norton)

Host plants - Wheat stem sawfly is a native species which lives in native grasses. It has often been a pest of wheat but will also attack rye. Oats and barley are rarely harmed by the larvae burrowing in the stems.

Overwintering - The sawfly larva feeds within the stem and burrows down to or below ground level by the time the wheat heads begin to ripen. It then turns around, head upwards, and cuts through the stem about an inch above the ground, seals the end above itself, spins a cocoon in the stem and passes the winter as a diapausing (hibernating) larva.

Spring appearance - Larvae pupate within their cocoons in May; adult sawflies emerge during mid-June to early July from stubble fields and native grasses. They are rather inactive insects which drift from plant to plant and spend most of their time resting on grass stems.

Number of generations - One per year.

Parasites - An ichneumonid wasp parasite, **Collyria calcitrator**, failed to become established in releases from 1930-1938 in Saskatchewan and Alberta. During the same period two other species of imported parasitic insects were released, also without success.

A native parasitic wasp, **Bracon cephi**, is one of the few wasps which can move from the grass to the crop with the sawfly. When weather conditions delay ripening of the crop (and so allow the wasp to produce two generations), parasitism by **B. cephi** can control sawfly infestations. The parasitic wasp, **Bracon lisogaster**, (a close relative of **B. cephi**) is a parasite of sawflies that attack grasses in the prairies. It is of significant help in controlling wheat stem sawfly in uncultivated situations.

Pathogens - Nuclear polyhedrosis, a virus disease which is an important natural control factor in sawfly populations, has potential as a biological control and is registered for use for a limited number of pests in the United States.

Economic importance - A serious pest of wheat in Saskatchewan and Alberta, wheat stem sawfly was estimated to have caused losses of about 50 million bushels in 1941 and 15-30 million bushels in 1944 and 1946. The development of solid-stemmed wheat varieties greatly decreased the importance of this pest.

Damage - The sawfly larva bores down inside the stem making a discolored tunnel from about the top joint to the root. When the egg is laid above the top joint, feeding by the larva can cause the head of the plant to turn whitish. This does not happen very often. The larva cuts the supply of nutrients to the top of the plant.

The greatest losses occur around the margins of fields. Wheat stem sawfly losses are of two types. Larval feeding within the stem of the plant reduces both the yield of the crop and quality of grain harvested (from reduced protein and kernel weight). Stem cutting by the larvae allows stems to break in the wind, fall to the ground and become unharvestable.

Sampling and monitoring methods - Determine percentage of plants cut by sawfly per square metre prior to harvest.

Economic threshold - Control methods are required if 10-15 per cent of the crop in the previous year was cut by sawfly.

Management strategy

Effects of weather - Most fluctuations in populations are caused indirectly by weather. The effects of rainfall or drought on the primary food plants, grasses, can be of major importance in determining the size of infestations in the secondary food plants, cereals. When rainy in the fall or spring, the numbers of large head-bearing stems of native grasses are adequate for sawfly populations, but, when there is a drought, the numbers of grass stems suitable for attack are few and the sawfly concentrates its attack on wheat instead of on grasses. Since only one sawfly will emerge per stem, a shortage of suitable oviposition sites will result in higher mortality from cannibalism. When rain promotes an abundance of suitable stems, the proportion receiving more than one egg is low and sawfly populations increase. Warm, sunny, windless weather, especially after rain, enables the sawflies to disperse widely instead of concentrating their attack near the field margins in fewer plants. Drought conditions can result in reduced infestation the following year by killing plants that have larvae inside them. Drought in the spring can cause overwintered larvae to re-enter diapause but the influence of this on population sizes is not clear. Abundant rainfall tends to produce outbreaks of stem rust disease which is harmful to sawfly larvae. In one instance only 18 percent of larvae in heavily rusted wheat survived. A general reduction in 1955 was attributed to high rainfall and severe rust infestations which killed the larvae in 1954. Hail can reduce infestations. In one instance there was a small infestation following a severe hailstorm but severe infestations persisted outside the hailed area.

Cultural controls - A number of control approaches have been implemented to reduce the losses caused by this insect. The use of solid-stemmed, resistant varieties of wheat tends to keep down the severity of sawfly damage because the larvae have difficulty surviving in these wheats. Swathing sawfly infested wheat as soon as kernel moisture drops below 40 per cent is also recommended to save infested stems before they fall.

Alternate crops, immune or resistant to wheat stem sawfly, may be grown instead of wheat. Such crops are barley, oats, winter wheat, flax, alfalfa and brome grass. A temporary trap crop of a susceptible variety placed around the crop and then swathed for hay or silage in July may help to remove some of the larval population. A permanent trap crop of smooth brome grass around a field will reduce the number of larvae surviving in ditches and headlands. Delayed seeding in spring produces a crop that is unattractive to females at egg laying time. Late maturing varieties allow production of two generations of parasites which result in fewer sawflies the following year.

Summerfallowing infested stubble and then cultivating in early June to bury pupating adults has been beneficial. Shallow tillage in fall will increase larval mortality and help reduce the sawfly population. Deep tillage will bury overwintering larvae and reduce adult emergence dramatically but the possibility of soil erosion is too great a risk for this practice to be widely recommended. Burning infested stubble may reduce sawfly numbers but it also greatly reduces parasite numbers and the benefits of returning stubble to the soil are lost. In view of other cultural control options available, burning is not recommended.

Continuous cropping of susceptible crops and reduced tillage will improve larval survival and therefore increase the risk of infestations in the future.

Biological control - Parasites are important in regulating sawfly populations. Various reductions in infestations have been attributed to heavy parasitism in the same or in the immediately preceeding years. Initially, sawflies in grain fields were apparently free of parasites; over time, the number of parasitized sawflies gradually increased. It was later found that different parasite species vary in their effects on sawfly populations, depending on whether the infested host plant is in a native or cultivated habitat. For instance, one species of parasite has a decided preference for larvae in grasses over larvae in cereals, perhaps because the adult parasites may have to feed on grasses before egg laying.

Weather can also influence sawfly numbers. Parasitism has increased when there has been above-average rainfall in August of the same or the preceding year. A possible explanation is that abundant soil moisture will delay ripening of the wheat and thus delay cutting of the stems by sawfly larvae. Apparently, larvae do not cut until the moisture content of stems falls below 50 per cent. The consequent prolongation of larval life gives more time for the parasites to attack. The adult parasites are inactive during and after rain but become quite active when the grass dries. In one instance an early ripening of wheat enabled sawfly larvae to cut the stems before the second generation of the chief parasite could attack them. This resulted in low parasitism the following year. Weather conditions that tend to increase the number of stems with more than one sawfly egg can result in parasite reduction because the first sawfly larva to hatch will eat parasite eggs as well as sawfly eggs. It is probably because of this that an attempt at biological control with imported parasites failed.

DISEASE CONTROL

DISEASE CONTROL — GENERAL

Effective disease control can be attained through the use of several methods. Control may not necessarily mean eradication of the disease, but rather decreasing it to a level where it is no longer an economical threat. Disease prevention, crop management practices, and disease resistance must be integrated into a disease management program to obtain effective disease control. Each management program must be specially tailored for each specific disease, crop, cropping system, location and production level.

SYMPTOMS OF DISEASE

Spot diseases of leaves and stems are caused by fungi, bacteria and environmental conditions. Generally, the size, shape and color of the spot is constant for the disease. Stem-eye spot of fescue is an example of a disease that causes distinctive spots on the flowering stems of fescue.

Blotch diseases appear as irregular shaped leaf lesions. Net blotch is one of the most common foliar diseases of barley in Canada.

Blight fungi typically kill young stems and roots. Seedling blights are common throughout the prairies. In some springs, large numbers of canola fields must be reseeded because of seedling blight. The disease is very active in dry cold soil conditions.

Scorch occurs during very hot weather. The sun causes a browning or bleaching of leaves. On cereal seedlings, this takes the form of distinct bleached bands called heat banding.

Wilting results from a deficiency of water in the leaves and stems, caused by drought, or the effects of root and stem diseases. Flax wilt is caused by a soil-borne fungus that attacks through the roots.

Damping-off fungi most frequently attack seedlings, killing the stems and roots near the soil line. The disease is active under wet or waterlogged soil conditions and causes infected plants to rot and fall over. Alfalfa seedlings are particularly susceptible.

Rots are caused by various organisms. Root rot of canola, caused by a fungus, is a common disease.

Smuts appear as black pustules that break out on cereals. Loose and covered smuts of barley, wheat and oats are common diseases.

LIVING (BIOTIC) CAUSES OF DISEASE

Infectious crop diseases on the prairies are caused by fungi, bacteria, viruses, and nematodes. They are referred to as microbes or germs. Other organisms that cause disease are unimportant to prairie agriculture.

Fungi - that feed directly on living plants and cause diseases are called PATHOGENS. Worldwide, more than 30,000 types or species of fungi cause plant diseases.

Fungi in an active stage of growth are composed of very fine hairlike, white or colored threads, growing together in a mat called mycelium. They are familiar as the fluffy growth on rotting food. Fungi reproduce by means of spores of various shapes, sizes and colors. These spores can be produced directly from the fluffy threads as in the case with bunt balls in wheat. These bunt balls are actually masses of spores. Spores may be formed in or on specialized structures called fruiting bodies. An example of which is the white stem rot fungus of canola (sclerotinia) which produces its spores in tiny mushroom-like structures.

Parasitic fungi are usually limited in the kinds of plants they attack. Covered smut is a disease of most cereals, but the species of smut fungi that infect wheat can not infect barley and vice versa.

Disease develops when a fungal spore is able to infect and grow on a healthy plant. The reaction of the plant to the fungus is the symptom of the disease.

Spores are the "seeds" in the life cycle of the fungus:

- they are the reproductive structures of the fungus
- they spread fungi to new locations
- they survive overwinter or other periods of adverse weather conditions.

Spores are dispersed by air currents, running water, splashing rain, insects etc.

Some fungi, such as sclerotinia and ergot (of cereals), produce special resting bodies called sclerotes or ergots. They are about the size of cereal grains and can survive in or on the soil for a number of years. Sclerotia or ergots germinate during moist summer weather and produce tiny mushrooms that release infectious spores. Sclerotinia spores attack crops like canola, sunflowers and beans, whereas ergot spores attack the flowers of cereals and grasses.

Bacteria - are invisible, single-celled organisms. They invade plants through natural openings or wounds. They need free water to enter natural breathing pores on plant leaves and stems. Bacteria can multiply quickly and are most destructive under moist warm conditions. They spread by splashing rain, plant to plant contact, on seeds or by insects.

They cause leaf and head blights, wilts, scabs, cankers and soft rots. They overwinter on seeds or plant residue.

Viruses - are visible under an electron microscope. They are found in all parts of infected plants. Many viruses are transmitted by insects such as aphids, leafhoppers and mites during feeding. Viruses cannot survive outside the host plant or insect vector. They overwinter in perennial or biennial weeds and in the case of a few viruses, inside seed embryos.

Nematodes - are like small worms. They may exist on organic matter in the soil or as parasites of plants. The life cycle of nematodes may take from weeks to months to complete, and has six stages: egg, four larval forms, and the adult. Nematodes are common in prairie soils, but are only a problem in a few crops. Stem nematodes can cause yield losses in irrigated alfalfa and cyst nematodes cause problems in sugar beets.

Nematodes survive in the soil as eggs or cysts which hatch when a suitable host is present. They are spread by man, wind, water, or animals. Nematode spread may be restricted by quarantine measures as is the case with the golden nematode of potatoes which occurs in soils on Vancouver Island and Newfoundland. Stringent quarantine measures on the movement of potatoes, other plant parts and soil have prevented this pest from being introduced to the rest of Canada.

NONLIVING (ABIOTIC) CAUSES OF DISEASE

Soil moisture - Drought is easily recognized. Plants are wilted or dried up and dead. A milder moisture deficiency is more difficult to recognize, especially if the plants are also affected by parasitic disease. Water stress weakens plant and makes them more susceptible to infectious diseases.

Excessive soil moisture deprives plant roots of oxygen causing death. Canola seeds in cold wet soil may rot during germination or produce weak yellow colored seedlings which are susceptible to infectious diseases. Alfalfa roots are sensitive to water logging and are killed by a week of flooding. Grasses may thrive for many weeks under water.

Fluctuation in soil water can cause irregular tillering in cereals.

Soil nutrient composition - Nitrogen is the most universally deficient nutrient for crops. Nitrogen deficiency limits chlorophyll development in canola, older leaves turn lighter green or yellow, wither and fall off. Plants are stunted and flowering period and seed production are reduced.

Excessive amounts of nitrogen can cause heavy vegetative crop growth. Dense crop canopies are conducive to many types of diseases and lodging, both of which are capable of reducing yields.

Sulphur deficiency occurs in canola especially on well drained, sandy and leached Grey Wooded soils. Affected canola leaves are cupped and purplish, flowers are paler yellow, and pods are poorly filled or missing. A deficiency of available manganese (usually in organic soils) causes gray speck disease of oats. Phosphorous deficiency in cereals will cause reddish or purple leaf discoloration and may predispose wheat seedlings to browning root rot. Potassium deficiency in alfalfa is recognized by white spots on the leaves. Copper deficiency in wheat predisposes plants to head discoloration (melanosis) and low grain yields. Copper is essential for seed set and development.

Potassium deficiency in canola is frequently seen when the weather is cool. Although soil tests may indicate that potassium is abundant, it is not released in a form that is available to plants at a fast enough rate when the soil is cold. This is particularly true during flowering when potassium demand is high.

Acidic soils (pH below 5) may have abnormally high quantities of minerals that interfere with normal plant growth. In addition, calcium needed for normal growth is often lacking in these soils. Alfalfa will not do well in soils below pH 6 because nitrogen fixing bacteria which produce the nodules on the alfalfa roots cannot survive. High pH (alkaline soils) may also limit the availability of certain micronutrients. Most crops do best when the soil pH is between 6 and 8.

Meteorologic conditions - Light stress can occur around heavily treed areas. Crop plants that do not tolerate shade grow tall and spindly and are susceptible to root rots.

Sudden changes in temperature can produce symptoms similar to those of an infectious disease. Blast of oats is caused by extreme heat or very cool weather shortly before the head emerges; seed-producing flowers are killed in the boot stage and no grain is formed.

Heat from the sun is greatest at the soil surface where it can damage the tender leaves or young stems of cereals and oilseeds.

Cold temperatures may damage many crops during the growing season (frost) or over the winter (winterkill). When the growing point of sunflowers or peas is killed by frost, new growth will begin from a dormant buds below the damaged area. This results in a distorted appearance or in the production of an excessive number of branches. Soil surface temperatures of -3° to -5°C for several hours can kill canola seedlings in May or June. Early fall frosts at temperatures of -1 to -2°C can reduce the quality and quantity of canola and cereal grain. Alfalfa and winter wheat can be killed when soil surface temperatures fall below -20°C.

Typically, wind, hail and lightning cause mechanical damage and leave crops more susceptible to infectious diseases.

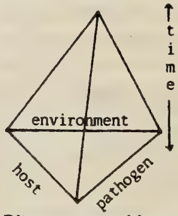
Toxic emissions - or their byproducts in the atmosphere can damage plants. For example, ozone in concentrations of more than 8 parts per million (ppm), which can be produced by severe thunderstorms, may heavily damage field beans. Sulfur dioxide emissions from gas plants, in concentrations of 5 to 10 parts per million (ppm), may injure crop foliage.

Mechanical injuries - that can result from almost every agricultural practice done the wrong way, at the wrong time or with the wrong implements can damage plants. Roots can be damaged by cultivation. Rough or improper handling of grain during combining, cleaning or drying can affect seed germination.

DISEASE DEVELOPMENT

In order for a disease to develop in a growing plant, there must be a number of factors in favor of that disease causing organism:

- there must be a susceptible HOST
- a favorable ENVIRONMENT
- the DISEASE organism must be aggressive and virulent
- sufficient TIME for infection - the longer the exposure time, the greater the probability of infection, e.g., six hours of continuous leaf wetness is required before spores of the tan spot fungus can infect healthy wheat leaves.



Disease pyramid
Nonchemical disease control attempts to remove one or more of these parameters to prevent disease development.

NONCHEMICAL SEED TREATMENT

Hot water treatment - This method must be carried out with extreme caution because it is easy to injure the seed. The seed is soaked in half filled loosely woven burlap sacks at 21 °C for 5 hours. Remove sacks, drain, place in water bath at 49 °C for 1 minute. Move to the next bath at 52 °C for 11 minutes. Then place sacks immediately in cold water. If the seed is to be stored it must be dried thoroughly.

Cold water treatment - Soak seed at 21-23 °C for 48-72 hours. This method has been shown to have some detrimental effect in seed germination. It has been reported that damage is less if a 1 to 2 per cent solution of common salt is used.

On a large field scale, water treatments are not very practical, but this system is successful in preventing seed borne diseases in vegetables.

Legume inoculation - Legume seed should be inoculated with nitrogen fixing bacteria specific to that species of legume e.g., beans, clovers and peas. Alfalfa seed should be inoculated with a bacterium called **Rhizobium meliloti.** The bacteria and alfalfa live in a symbiotic relationship, the bacteria fixing atmospheric nitrogen in the alfalfa root nodules and exchanging it with the plant in return for nutrients and sugars. Under certain conditions, some soils may contain high natural levels of these specific nitrogen fixing bacteria so that inoculation is not needed every time legume seed is sown. Legume inoculant is particularly recommended to ensure vigorous stands - all legume seed should be inoculated.

MYCOPARASITISM

This is a form of biological control where one fungus parasitizes another fungus. However, many fungi that really parasitize other fungi under laboratory conditions fail to do so in natural soils. At least two fungi (**Coniothyrium minitans** and **Talaromyces flavus**) have been shown to parasitize the Sclerotinia fungus, the cause of white mold of canola. They occur naturally in the field but their ecological significance and the extent they parasitize the white mold fungus is not known.

INTERFERENCE

Scientific work is underway investigating the possibility of using the concept of interference to protect plants against disease. By inoculating the host plant with a mild strain of disease or a similar organism to the disease-causing organism, the plant may not be affected by the virulent strain of disease. The fungus **Phialophora graminicola,** which is closely related to the take-all fungus, colonizes the same place on the wheat roots but causes no disease. Once colonized by **P. graminicola,** the take-all fungus can not infect the wheat plant. Mycorrhizal fungi, which occur naturally in the soil in association with plant roots, can act as a protective barrier against infection by **Pythium, Phytophthora** and **Fusarium** species. Currently experiments are continuing on the use of bacteria such as **Bacillus** species as seed treatments on canola for the prevention of seedling blight. Presumably the free living, nondisease causing **Bacillus** species would thrive in the soil around the planted seed and protect it from disease-causing organisms, such as **Rhizoctonia.**

Plant diseases are usually less severe on soils with a high organic matter content. This is not only because of increased plant vigor, but there is an antagonistic effect of various other soil microorganisms which become more active in the presence of organic matter.

DISEASES OF CEREALS

(Barley, Oats, Rye, Triticale, Wheat)

SEEDLING AND ROOT DISEASES

COMMON ROOT ROT (SEEDLING BLIGHT, DAMPING OFF)

Cochliobolus sativus, Fusarium spp., **Rhizoctonia** spp. **Pythium** spp.

Biology - Common root rot is consistently one of the most damaging diseases of wheat and barley. It can also infect oats, rye and triticale. There are a number of phases to this disease complex; seedling blight, root rot and later in the season, a possible leaf spot phase. The seedling blight phase is less common on wheat than barley. In the mature plant, root rot caused primarily by **Cochliobolus sativus** is the major cause of crop loss. The leaf spot and head infection phase is less important on the prairies than in the eastern provinces.

Disease cycle - Initial infections originate from soil-borne spores. Seedlings become infected following germination and further infections continue throughout the growing season. Abundant spore production occurs on diseased tissue. Spores are spread by wind, water, cultivation and through infested or infected seeds. Spores may remain viable in soil for several years, until stimulated to grow by the presence of a host plant.

Disease development - Cold soils, as well as drought and high temperature stress are important predisposing factors.

Symptoms - Patchy emergence is usually the first indication that damage has occurred. Brown spots appear on the roots, subcrown internodes (part of plant between the seed and crown) and leaves. Infected plants may be stunted. Seedlings may die before or soon after emergence even though they appear to only show slight damage.

Detrimental effects - Common root rot and crown damage lower yields. Infected plants tend to produce fewer tillers with smaller, fewer seeds per head. There may be some premature ripening. Root rot in barley and wheat has been estimated to cause average annual yield losses of 10 per cent and 5.7 per cent, respectively.

Threshold levels - Cereal crops can withstand a certain amount of seedling blight. The extra space, water, nutrients and light that would have been used by missing seedlings is taken up by neighboring plants to produce more tillers with larger heads and kernels compensating for the loss. No definite threshold levels are available.

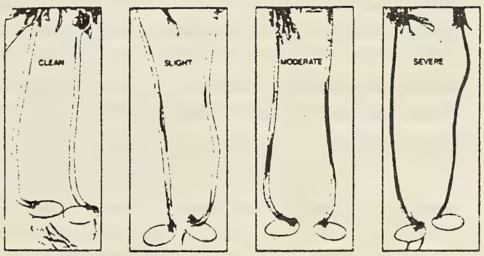
Sampling - The presence and severity of this disease can be determined by pulling up plants and examining the crowns and subcrown internodes for disease.

Procedure: Sampling for **C. sativus** damage on common wheat. Collect 100 plants, comprised of randomly selected groups of 5-10 plants each and rate the disease level on the crown and subcrown internode

Clean (0)	=	no brown spots (lesions)
Slight (1)	=	up to 25% of area with lesions
Moderate (2)	=	25-50% of area with lesions
Severe (4)	=	more than 50% of area with lesions

Use the formula $\frac{(a + 2b + 4c)}{10}$, where a, b, c are the Frequency of (a) slight-1, (b) moderate-2, (c) severe-4 in the 100 plants sampled. This gives an estimated yield loss as a percentage. Thus, if there were 25 plants in each of the slight, moderate and severe catagories, the yield loss estimate equals 17.5%, calculated as follows:

$$\frac{25 + 2(25) + 4(25)}{10} = \frac{25 + 50 + 100}{10} = \frac{175}{10} = 17.5\%$$



(0) No lesions — (1) Up to 25% of the area with lesions — (2) 25-50% of the area with lesions — (4) more than 50% of the area with leasions

A modification of this method only uses two disease categories: clean to slight and moderate to severe. The percentage of plants in the second group is the rating. This multiplied by 0.4 equals estimated percentages yield reduction. If 40 per cent of the plants are in the moderate to severe category, then the yield loss would equal 0.4 x 40% or 16%.

These methods may be used to obtain a disease rating for barley, durum wheat and rye, but no specific information is available for guidance in the conversion factor used to estimate yield loss.

Management Strategy - Reduce infectious spore levels in the soil.

Control Mechanism

- Long rotations with oats or noncereal crops.
- Avoid deep seeding which reduces plant vigor - a healthy vigorous plant is more likely to avoid or cope with root or crown infections.
- Adequate levels of fertilizer especially phosphorus will reduce disease severity. In some instances, potassium chloride fertilizer has been shown to significantly reduce root rot levels - more research is needed before any recommendations can be made.
- Use quality seed.
- Turning under of stubble may slightly reduce infection levels.
- Use resistant varieties.

WINTER INJURY (winterkill)
Environmental stresses

Cottony snow mold - **Coprinus psychromorbidus** (LTB and SLTB phase)
Gray snow mold - **Typhula incarnata**
Pink snow mold - **Fusarium nivale**
Speckled snow mold - **Typhula ishikariensis** var. **ishikariensis, T. ishikariensis** var. **canadensis**
Sclerotinia snow mold - **Myriosclerotinia borealis**

Biology - The most important cause of winter wheat damage in Alberta is winter injury or winterkill, these are terms used to describe damage from disease or environmental stress. All cold hardy winter wheat varieties are susceptible to several snow mold fungi. These fungi cause severe damage under snowcover during conditions that are favorable for disease development. Cottony snow mold fungi are found throughout Alberta, while sclerotinia snow mold is common in the central and northern areas. This fungus can cause damage on snow-covered frozen soil.

When there is little or no snow cover, winter wheat can be damaged by environmental stresses, such as sub-freezing temperatures, standing water, ice encasement, heaving and desiccation. In southern Alberta, warm chinook winds may rapidly melt the protective snow cover, causing dehardening of the plants and exposing them to drying winds and frosts.

Disease cycle - These fungi overwinter as sclerotes (tiny black structures that are the overwintering bodies) or as a fungus in soil or crop residue. Some such as **S. borealis** are an endemic disease of wild grasses. Each snow mold has a specific geographic distribution on the prairies and a set of environmental factors that favor its growth.

Disease development - Snow molds are most damaging when an early snow cover on unfrozen soil persists throughout the winter, maintaining high humidity and temperatures of about 0°C at soil level. Snow molds grow quite actively at temperatures near freezing.

Symptoms - Because of the complexity of the causal factors involved, the diagnosis of winter damage is difficult when growth resumes in the spring. Damage is often assessed on the basis of symptoms and a knowledge of the terrain, soil conditions, management practices and weather conditions since seeding. Injury from standing water and ice encasement can be expected in heavy or poorly drained soils when freeze-thaw cycles and rain have occurred during the winter. Desiccation injury often occurs on exposed hills and on bare, windswept fields. Damage from snow molds is most prevalent and damaging following a long, snowy winter, especially where snow has accumulated in drifts. Snow mold damage may occur in discrete patches, in large areas, or it may cause thinning of the stand within the rows.

Detrimental effects - Winter injury damage may range from one or two dead tillers per plant to large areas of dead plants within each field. In 1983, snow molds destroyed 80 per cent of the fall rye in the Peace River region.

Threshold level - Five or more plants per square metre must remain alive in order to produce an average yielding crop. As long as the cereal crowns remain alive, new leaves and roots can be regenerated.

Sampling - Examine fall seeded crops in April. A quick way to determine if plants are alive is to remove some sample crowns from the field, place them in a closed plastic bag and leave in a warm room. Crown tissue which is severely damaged will quickly turn brown in a day or so while healthy tissue remains white.

Management Strategy - Use tolerant varieties and produce an environment unfavorable for the disease organism.

Control Mechanisms

- Cultivars of hard red winter wheat recommended for southern Alberta are more tolerant to ice encasement than those grown elsewhere.
- Do not plant winter wheat too late in the season. Plant resistance to winter injury depends largely on whether they have accumulated enough carbohydrate reserves in the crown and whether they are fully cold hardened before the onset of winter. The last week of August and the first week of September are considered the optimum planting times.
- Avoid heavy applications of nitrogen in the fall. Use adequate amounts of phosphorus for vigorous root growth.
- Seed into a stubble crop to help trap a light protective cover of snow. Ten centimetres of unpacked snow can prevent soil temperatures from falling below -11°C, even during the coldest periods of winter.
- Shallow seed (less than 4 cm) into a firm moist seedbed.
- Soot, powdered coal and printers ink have been spring applied to snow covered fields in the U.S.A. (late March - early April).This melts the snow quicker and has shown promise for control of snow mold damage.

BROWNING ROOT ROT (Pythium root rot)
Pythium spp.

Biology - All spring and winter cereals, along with forage grasses can be affected by browning root rot. The rot is caused by one or more **Pythium** species. This disease was the cause of major losses in wheat crops that were grown after fallow in the 1950s.

Disease cycle - The fungus spores can remain in the soil and crop residue for five years or more. The spores germinate, invade the roots and cause localized infections. New spores are produced in infected plant parts.

Disease development - Browning root rot is most common on wet soils low in phosphorus and organic matter with a previous history of cereal crops.

Symptoms - This disease occurs in patches. Infected plants become pale green, lower leaves turn yellow then brown. Plants are slightly stunted. Diseased plants have fewer tillers, poor root growth and delayed maturity. Soft wet brown lesions develop on the younger roots at or near their tips.

Detrimental effects - Infection during autumn or spring can kill young seedlings but late season infection usually causes a temporary setback. Yields may not be significantly affected.

Threshold levels - A few isolated diseased areas in a field may be a warning sign of low amounts of organic matter and available phosphorus.

Sampling - A soil sample submitted for laboratory analysis would give the phosphorus levels and organic matter content.

Management Strategy - Make the soil environment unsuitable for pathogen.

Control Mechanisms

- Maintain adequate phosphate levels or balance the nitrogen:phosphate ratio to promote root growth.
- Increase organic matter by incorporating straw or manure.

TAKE-ALL (charcoal root rot)
Gaeumannomyces graminis

Biology - Take-all is primarily a disease of wheat but barley, oats, rye and a number of grass species can also be affected.

Disease cycle - The fungus overwinters on infected crop residue. In spring, the fungus grows in the soil, comes into contact with the crop roots and causes infection. The fungus may grow from root to root infecting new plants. Infection may occur throughout the growing season, but the early infections are the most damaging because they move up into the plant crown. This disease organism is spread by transport of infested soil or crop residue from field to field.

Disease development - Favored by soil temperature of 12-20°C and high soil moisture. Alkaline soils, compacted poorly drained soils, and nitrogen and phosphorus deficient soils increase disease severity.

Symptoms - Roots of infected plants are dark brown to shiny black and so rotted that plants can easily be pulled from the ground. Stems may also show this shiny black discoloration. Severely diseased plants are stunted with empty bleached white heads. These white heads stand out in patches in the crop.

Detrimental effects - Take-all is most severe after wheat is grown in the same field for two to four years. Light infestations may go unnoticed, but under severe infestation levels, wheat losses of greater than 30 per cent have been recorded.

The disease is named take-all because all obviously affected plants fail to produce seed.

Threshold levels - The disease kills headed out plants and in spring sown wheat, a 62 per cent infection of take-all reduced yields by 50 per cent. On spring sown barley a 64 per cent infection of take-all reduced yields by 24 per cent. This disease is progressive, spreading from plant to plant throughout the growing season.

Sampling - Diseased plants have bleached white heads that pull up easily, with shiny charcoal black crowns and roots.

Management Strategy - Avoid build-up of this disease on crop land.

Control Mechanisms

- Rotate crop with nonhost crops such as canola or flax or less affected cereal crops. Cereals in order of decreasing susceptibility are wheat, barley, triticale, rye and oats. Planting alfalfa, beans or soybeans in the rotation may not help reduce disease levels. Summerfallow reduces disease incidence in the following wheat crop.
- Maintain adequate nutrient levels especially phosphorus and potassium. Liming of acid soils as well as applying nitrate nitrogen to winter wheat in the fall may increase disease severity.
- Control volunteer wheat and grassy weeds which may harbor the fungus.
- Deep till to bury stubble for faster decomposition.
- Avoid transporting infested soil or crop residue when moving equipment from field to field.

  Research experiments have been conducted in the United States on treatment of wheat seed with **Pseudomonas fluorescens** bacterial cultures prior to planting. Results to date have shown that bacteria-treated seed gave up to a 10 per cent increase in yield over untreated checks. Further research is needed to see if this method of control is economically justified.

STEM DISEASES

SHARP EYESPOT

Rhizoctonia solani - R. cerealis

Biology - Sharp eyespot occurs on the lower stems of cereals and some grasses. Wheat is more susceptible than barley, oats, or rye, and winter cereals are more susceptible than spring cereals.

Disease cycle - The fungus overwinters on crop residues as a nonspore producing mycelium. The sharp eyespot fungus has a wide host range and infects plants directly through the soil. The eyespot fungus **Pseudocercosporella herpotrichioides** causes similar damage on winter wheat in Ontario but is not known to occur in western Canada.

Disease development - Severity can be high, particularly on light, dry, acid soils during cool springs.

Symptoms - At the base of stems at heading, distinct grey to brown spots with dark margins appear. The spots spread outwards and the centres darken. Dark fungus that can be rubbed off may be present in the centre of the lesion. Stem breakage, white heads and lodging can occur as a result of this disease.

Detrimental effects - Sharp eyespot can kill tillers or entire plants. Most often it reduces kernel size and number and causes plants to lodge, making crops difficult to combine. It increases the risk of head diseases, grain sprouting and weed growth. Moderate disease levels in the crop result in affected plants being supported by their healthy neighbors. In severe cases, large areas will lodge. Lodging is nondirectional and unlike wind lodged crops, does not allow some recovery.

Threshold levels - No data available.

Sampling - Check the stem breakage area for the presence of this fungus. Under some conditions, a postemergence herbicide application may have been responsible for the lower stem breakage.

Management Strategy - Reduce soil-borne fungus levels.

Control Mechanisms

- Use crop rotations with a noncereal crop or use lower risk cereal crops for two-three years to reduce levels of the fungus in the soil.
- Use management practices such as deep cultivation which shorten residue decomposition time.
- There are no resistant varieties. Use wheat types with stiffer straw or solid stems that are better able to withstand stem breakage.

STEM SMUT

Urocystis occulta

Biology - Stem smut affects only rye and is fairly rare except in areas of southern Alberta where the disease has caused significant yield losses on fall rye. This disease is seldom a problem on spring rye.

Disease cycle - Spores persist for a year or so in soil, crop residues and on the seed. The fungus infects the fall-sown rye and grows inside the plant. Infected seedlings may die before reaching maturity. The smut fungus produces spores on the top leaves, stems and heads. Spores fall to the ground or are dispersed by the wind onto adjacent land. During combining, spores will contaminate healthy seeds.

Disease development - The fungus is favored by low soil moisture and temperatures between 10° and 20°C.

Symptoms - Just before heading, long grey-black streaks which contain masses of spores, appear on leaf blades, sheaths, upper stems and heads. Heads may fail to emerge or become distorted, forming shepherd's crooks. Infected tillers are stunted, sometimes appearing alongside healthy tillers from the same plant.

Detrimental effects - Infected plants produce little or no grain. In Alberta between 1977 and 1981, the loss in yield from this one disease was estimated at $1.25 million. The ability of this fungus to survive at least a year in dry soil, failure to use fungicidal seed treatments, and the use of susceptible varieties led to the build-up of this disease.

Threshold levels - No data available.

Sampling - Infected plants are easily identified at the heading out stage. Percentage infection can be easily calculated via infected tiller counts.

Management Strategy - Reduce levels of soil borne fungi.

Control Mechanisms

- Use resistant varieties.
- Use crop rotation - Include fall rye only once in every three years to avoid soil-borne smut spores.
- Use clean seed from a known disease-free source.
- Do not plant rye adjacent to a previously infected field as the soil could be infested by windblown spores.

FOLIAR DISEASES

ANTHRACNOSE
Colletotrichum graminicola

Biology - Anthracnose is a disease of cereals and grasses. It is not very common in Canada, but has been reported on oats in north-central and western Alberta. It infects all parts of the plant.

Disease cycle - Spores of this fungus overwinter on the seed and crop residue. Initial infection usually results from soil-borne inoculum. Upper plant parts are usually infected later in the season from spores spread by splashing rain or wind.

Disease development - Poor soils, high pH and wet weather favor spore production. Crops that are nutritionally stressed are especially susceptible.

Symptoms - On oats: Brown lens-shaped spots appear on the leaves. Crown and lower stem areas become bleached, then turn brown. Small black dots (sexual fruiting bodies) are produced on dead tissue.

Detrimental effects - Crown infections reduce plant vigor and cause premature ripening. There is also increased lodging caused by constrictions at the base of the tillers. This disease is generally of little economic significance in the prairie provinces.

Threshold levels - No data available.

Sampling - If disease is present, check soil pH and fertility levels.

Management Strategy - Reduce spore levels and promote an environment unfavorable to the pathogen.

Control Mechanisms

- Maintain soil fertility by applying recommended levels of fertilizer and by using soil improving rotations.
- Use crop rotations with noncereal crops for at least two years.
- Control grassy weeds as well as headland grasses.
- Turn under crop residue to reduce spore levels.

BACTERIAL BLIGHT
Xanthomonas campestris pv. translucens

Barley - bacterial streak and black chaff
Oats - halo blight - **Pseudomonas syringae** pv. **coronafaciens**
- stripe blight - **Pseudomonas syringae** pv. **striafaciens**

Rye - bacterial blight - **Xanthomonas translucens**
Wheat - bacterial stripe and black chaff - **Xanthomonas translucens**
- basal glume rot and bacterial black point - **Pseudomonas atrofaciens**
- bacterial leaf blight - **Pseudomonas syringae** pv. **syringae**

Disease Control

Biology - Bacterial blight, caused by several different species of bacteria, can cause head and foliar diseases of barley, oats, rye and wheat.

Disease cycle - The disease-causing bacteria overwinter on crop residue, seed, fall sown cereals and perennial grasses. Spring infection may result from any of these sources. Bacteria are spread by splashing rain drops, plant to plant contact or insects.

Disease development - The disease is favored by cool, wet weather. Warm dry weather checks bacterial diseases and new emerging leaves may be relatively free of bacterial infection.

Symptoms - On barley: Bacterial streak begins as small pale green spots which become water soaked. These join to form transparent stripes. Later, the stripes turn yellow or brown. A milky exudate may be present on the leaves under wet conditions. When dry, this exudate turns into small thin flakes which are easily removed from the leaf surface.

On oats: Halo blight begins as small light green oval spots with dark water-soaked centres. The spots join to form an irregular brown blotches. Stripe blight produces elongated spots with no pale margins. These spots also have water-soaked centres and turn brown later in the year.

On wheat: Bacterial stripe produces dark green, water-soaked lesions that later turn brown. Near heading, symptoms appear on upper leaves as water-soaked spots that grow to whitish streaks or blotches (white blotch).

Black chaff appears on the kernels as dark stripes on the glumes. These often join and the glumes turn black. These symptoms occur on both wheat and barley.

Basal glume rot appears mostly on the inner side of the glumes as a light brown color. As the disease develops, the grain may develop a blackspot at the germ end, known as bacterial black point.

Bacterial leaf blight appears on the flag leaf when bright sunny weather follows a rainy period. This disease occurs occasionally on winter wheat.

On rye: The bacterial disease symptoms appear very similar to those described for barley but exudate on the leaves is not as common.

Detrimental effects - Plant infections result in a lower photosynthetic area reducing yield. Kernel discolorations may also result in dockage or downgrading of the grain quality. Bacterial blight infestations are usually localized within the field and do not usually cause major field scale damage.

Threshold levels - No data available.

Sampling - Bacterial infections are most obvious and easily diagnosed immediately following prolonged periods of wet weather.

Management Strategy - Avoid infesting clean fields and reduce levels of bacterial infection.

Control Mechanisms

- Use seed from crops free of bacterial disease.
- Use crop rotation with noncereal crops. Rye should not follow wheat or rye, and barley should not follow barley.
- Burn infected wild grass along headlands before sowing winter rye.
- Use resistant varieties when available; none of the presently grown cereals have been evaluated.

BARLEY STRIPE (fungal stripe)
Pyrenophora graminea (asexual **Drechslera graminea**)

Biology - Barley stripe can potentially cause very heavy yield losses in two and six-row barleys. Other cereals are not affected.

Disease cycle - This fungus is exclusively seed-borne and overwinters inside the seed. The fungus grows internally within the infected plant. Spores are produced on the infected leaves and are spread by wind to nearby healthy heads. The seeds can become infected at any time but are most susceptible during early development.

Disease development - Infection of seedlings is higher when soil temperatures are 15°C. Sporulation on the foliage of infested plants is encouraged by periods of high humidity.

Symptoms - Vivid longitudinal yellow stripes bounded by the veins, appear on the leaves, extend from the base of the leaf to the tip. The stripes eventually become brownish and infected leaves tear and fray. Infected plants are stunted and heads become twisted, blighted or fail to emerge.

Detrimental effects - The yield loss is directly proportional to the percentage of infected plants.

A 1 per cent infection level in the crop results in a 0.7 per cent direct yield loss. Some crop compensation occurs from neighboring healthy plants.

Threshold level - No data available.

Sampling - Infected plants stand out in the crop just prior to heading out. After heading out, infected plants may be "lost" under the canopy. Seed may be sent out to Agriculture Canada Seed Laboratory in Ottawa in order to determine percentage infection. See section under Certified Seed.

Management Strategy - Use disease resistant varieties and avoid infested seed.

Control Mechanisms

- Use disease-free seed if possible.
- Use resistant varieties.

CEPHALOSPORIUM STRIPE
Cephalosporium gramineum

Biology - Winter wheat is the major economic host. Spring cereals and annual grasses (**Bromus, Dactylis, Poa** spp.) are susceptible but infections rarely build-up to economic levels.

Disease cycle - The fungus survives within 8 cm (3 in.) of the soil surface on host residue. Spores germinate, invade roots via wounds caused by insects, soil heaving, or other mechanical stresses, and move through the plant water-conducting system to the stem nodes and leaves.

Disease development - Cephalosporium stripe is favored by cool, moist autumns, with fluctuating winter temperatures that result in stop-start growth cycles of the crop.

Symptoms - Diseased plants are usually scattered randomly around the field, usually concentrated in low wet spots. Longitudinal yellow stripes appear through the leaf, sheath, and stem. Veins within the stripe remain green. Stripes become brown and dark areas are formed at the nodes. Infected plants are stunted, and produce white heads. Infection stripes may not appear on all tillers of individually infected plants.

Detrimental effects - The presence of the fungus inside the cereal stems and leaves interferes with the flow of water and nutrients. Yield losses result from reduced seed set and kernel size.

Reports of disease levels of 80 per cent and yield reductions of 50 per cent have been reported in the United States. In Alberta, this disease is not known to cause significant yield losses.

Threshold levels - No data available.

Sampling -No procedure.

Management Strategy - Reduce soil-borne fungus levels.

Control Mechanisms

- Use a crop rotation of two or three years with legumes, corn, canola or spring cereals.
- Burn or bury infected residues to a depth below 8 cm (3 in.).
- Control grassy weeds in the crop and headlands.

GREY SPECK
Manganese deficiency

Biology - This is a nonparasitic disease caused by manganese deficiency. Soils may be deficient in the micronutrient or the manganese may be present in a form unavailable for plant uptake. Grey speck occurs in scattered areas throughout western Canada. This disease occurs mainly on oats and rarely affects barley or wheat.

Disease cycle - A nonparasitic disease.

Disease development - This condition is associated with neutral to alkali soils high in organic matter. The disease rarely occurs on soils with a pH below 6. Wet, poorly drained soils cause an increase in disease severity.

Symptoms - The deficiency symptoms appear as brown, unthrifty patches of oats. The first indication of the disease is usually seen at the four-to-five leaf stage as light grey oval spots on the leaves, which become irregular in shape and turn light brown. Spots usually appear about halfway down from the leaf tip, sometimes causing the leaf to breakover and die.

Detrimental effects - The degree of yield loss is relative to the unavailability of manganese. Grey speck is usually considered of minor importance but can cause crop failures in some areas. Loss of photosynthetic area and in some instances failure to produce heads contribute to yield loss.

Threshold levels - No data available.

Sampling - Take a soil sample and have the manganese levels analyzed.

Management Strategy - Overcome the deficiency.

Control Mechanisms

- Use oat varieties known to be tolerant to manganese deficiency.
- Wheat and barley are much less affected by this deficiency and should be grown as alternatives.
- Spraying the crop with 1 per cent manganous sulfate will reduce losses, but it is not economically practical.

NET BLOTCH

Pyrenophora teres (asexual Drechslera teres)

Biology - Net blotch is a common and destructive foliar disease of barley in western Canada, second only to scald as a cause of yield loss. Net blotch is more common than scald in the warmer drier regions of the prairies.

Disease cycle - The fungus overwinters on the seed or crop residue. Spores are produced and spread by wind and rain. Spores produced on infected plants are mainly responsible for destructive secondary spread of the disease within the crop.

Disease development - Seedling infection is greatest during periods of cool humid weather (10-15°C). Spore production and infection of the growing crop is favored by high relative humidity and temperatures around 20°C.

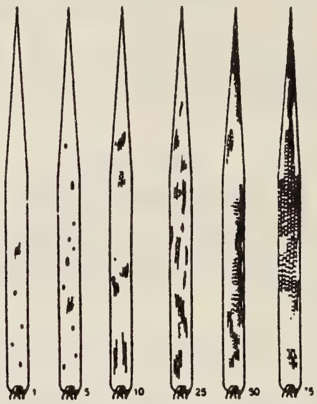
Symptoms - Light brown spots with distinctive dark brown net-like patterns appear on the leaves, sheaths and glumes. Spots enlarge and join into dark brown stripes. There is also a spot producing form of this fungus, which produces dark brown spots surrounded by a yellow zone. Symptoms vary with variety and weather conditions.

Detrimental effects - Yield loss is proportional to the amount of leaf area destroyed on the upper two leaves. The average yield loss in Alberta was calculated to be 1.5 per cent. Losses of 50 per cent and more have been recorded on highly susceptible varieties such as Elrose. Net blotch lowers grain yield and brewing quality by reducing the carbohydrate content of kernels. An estimate of yield loss can be obtained by using the crop loss formula developed for barley scald.

Threshold levels - No data available.

Sampling - Use the barley scald assessment procedure.

Percentage of leaf area affected



Management Strategy - Use resistant varieties and reduce disease levels in crop residue.

Control Mechanisms

- Use resistant varieties.
- Follow a crop rotation for at least two years with nonsusceptible hosts. Barley should not follow barley, particularly if disease levels were high the previous year.
- Use disease-free seed if possible. Seed may be sent to Agriculture Canada Seed Laboratory in Ottawa in order to determine percent infection.
- Turn under barley residues.
- If barley must be grown in two successive years, use the susceptible variety the first year and a resistant one the second.

POWDERY MILDEW
Erysiphe graminis

Biology - Powdery mildew as a group is one of the most common, widespread plant diseases. It can be very destructive on wheat and barley and to a much lesser extent on other cereals and grasses. The powdery mildew fungus is made up of different races and forms that are highly specialized, even down to the variety of wheat or barley they can attack. Wheat varieties might be resistant to a certain race of the mildew fungus, but susceptible to another race.

Disease cycle - This fungus overwinters on crop residue. Spores are dispersed in early spring by wind and infect susceptible plants. Secondary infections within the crop result from spores produced abundantly on the white mildew that covers the surface of infected plant parts.

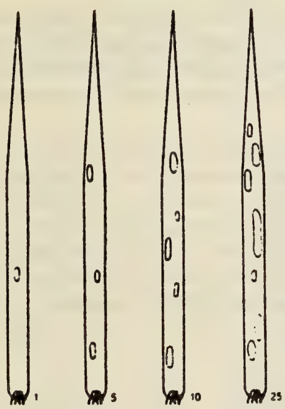
Disease development - Development is rapid in warm humid weather. This fungus is unique in that spore production and infection can take place in the absence of free moisture. Heavy rains are not favorable to spore production or fungal growth over the leaf surface. Rapid growth and dense foliar canopies caused by high nitrogen fertilizer application encourage disease development.

Symptoms - Powdery mildew attacks the leaves but stems and heads are also affected. The fungus grows primarily on the surface of the host, feeding on the living green cells of the cereal plant. Small, white or gray tufts of spore-producing fungus are most prevalent in the early part of the growing season on the upper surface of the lower leaves. Tissue on the opposite sides of the leaf turns pale green to yellow. The fungal tufts enlarge, join up and may turn a reddish brown. Later, this fungal growth becomes dotted with black pepper-like sexual bodies which enable the fungus to survive between growing seasons.

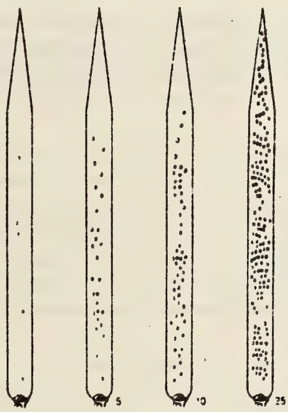
Detrimental effects - Damage to the plant occurs by reducing photosynthetic ability by shading the green surfaces and by robbing the host of moisture and food. Yields may be reduced by 20 per cent or more. Mildew affected cereals produce fewer tillers and grains per head and the grains may be poorly filled. On the prairies, barley, durum, hard red and prairie spring wheat are seldom affected at economic levels. Winter wheats are affected to a greater degree and considerable losses have occurred in some seasons on soft white wheats. The disease will seriously reduce yields if the flag and second leaf are affected. See scald of barley for yield loss formula.

Threshold levels - No data available.

Sampling - Use the barley scald assessment procedure.



Percentage of leaf area affected — Barley



Percentage of leaf area affected — Wheat

Management Strategy - Grow resistant varieties and reduce disease carryover through crop rotations.

Control Mechanisms

- Use resistant varieties.
- Follow a crop rotation of at least one to two years, or grow other types of wheat.
- Bury crop residue and destroy volunteers.
- Use balanced applications of nitrogen and phosphorus. Heavy nitrogen applications generally produce conditions favorable to outbreaks of this disease.

RUSTS

Stem rust - barley - **Puccinia graminis** f. sp. **secalis, P. graminis** f. sp. **tritici**
- oats - **P. graminis** f. sp **avenae**
- rye - **P. graminis** f. sp. **secalis**
- wheat and triticale - **P. graminis** f. sp. **tritici**

Leaf rust - barley - **P. hordei**
- oats (Crown rust) - **P. coronata**
- rye, triticale and wheat - **P. recondita**

Stripe rust - wheat and barley - **P. striiformis**

Biology - Many species of rust can affect barley, oats, rye, triticale, wheat and grasses. Each rust species is made up of a number of strains which differ only in their ability to infect certain host crop varieties. Both stem and leaf rust require two different unrelated host species to complete their life cycle, while stripe rust has no known alternate host.

Disease cycle - Since the alternate hosts for stem and leaf rust are not found in Alberta, infectious spores must be blown from rust infected crops in the United States. These rust spores directly infect susceptible cereal crops. A single spore pustule on a cereal leaf or stem may produce millions of infectious spores which can infect other susceptible cereals.

It is suspected that the stripe rust fungus has occasionally overwintered in Alberta as the infectious brown spore stage on susceptible winter wheats such as Norstar. Infectious brown spores from infected winter wheat are able to infect susceptible varieties of soft white wheat earlier in the season, with a high potential for considerable damage.

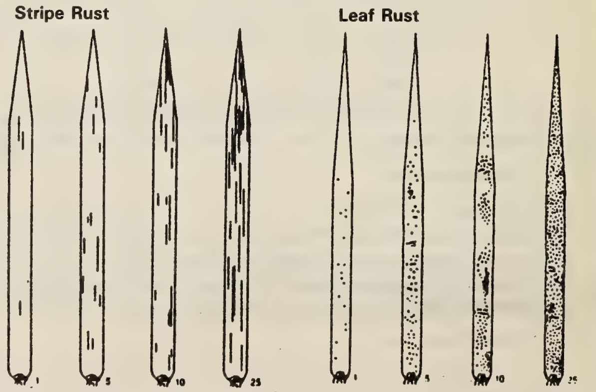
In the case of stem and leaf rusts, there may be some infection late in the season, but it is of no consequence the next year. This is because the brown summer infectious spores die out on the crop residue and the black overwintering spores can only infect the alternate hosts which do not exist in this province.

Symptoms - Stem rust produces reddish brown, elongated pustules on the stems, leaves, glumes, awns and kernels. These contain masses of brown spores. As the plant matures later in the season, the pustules start to produce black overwintering spores.

Leaf rust appears as small, round, orange pustules on leaves and leaf sheaths. As the plant matures, the pustules turn dark gray.

Stripe rust develops as elongated, yellow-orange pustules in rows of varying lengths. This gives the appearance of narrow yellow stripes mainly on the leaves and on the grain heads. These later become dark brown pustules, which produce the overwintering spores. Crown rust of oats is similar to leaf rust of wheat and barley except that the pustules may be present on both sides of the leaves and on the glumes. These are later replaced by black pustules.

Detrimental effects - Rusts, except for stripe rust in Alberta, do not usually cause significant yield losses because the spores arrive too late in the growing season to do much damage, except on susceptible late-seeded and late-tillering crops. Yield losses depend on the crops' growth stage at the time of infection and the amount of leaf tissue destroyed. Early infection of upper leaves, stems, and heads can cause high yield losses in the form of shrivelled grain, reduced baking quality and impaired germination. Serious damage from stem and leaf rust in most years occurs only in Manitoba and sometimes eastern Saskatchewan. Western Saskatchewan and Alberta usually escape losses from these rust diseases. These diseases can be assessed in the same way as scald of barley.



Percentage of leaf area affected   Percentage of leaf area affected

Threshold levels - No data available.

Sampling - Use barley scald assessment procedure.

Management Strategy - Use resistant varieties and avoid the disease.

Control Mechanisms

- Use resistant varieties.
- There are two types of resistance to stripe rust: seedling resistance and adult plant resistance. Seedling resistance lasts for the life of the plant whereas adult plant resistance only develops between booting and heading. Disease progresses rapidly until adult plant resistance starts, then the advancement of the disease slows dramatically. No licensed varieties have this latter form of resistance.
- Use early seeding and early maturing varieties that complete most of their development before being infected.
- Destroy alternate hosts for stem and leaf rusts to reduce inoculum levels.
- Avoid planting susceptible spring varieties near possible stripe rust-infected winter wheat fields.

SCALD

Rhynchosporium secalis

Biology - Scald is the major foliar disease of barley in the wetter regions of the prairies, particularly the parkland zone of Alberta. This disease can also affect rye and some grasses.

Disease cycle - The scald fungus overwinters on barley residue, grain and grasses, particularly species of **Bromus.** In spring, spores are produced mainly from the previous years' barley residue left on the soil surface. Spores produced on infected leaves are transported to other barley plants by rain drops and blowing wind. Scald can attack a growing barley plant at any time but levels of infection are usually most severe just before and during heading. The significance of scald-infected seed as a source of disease spread in barley is not well understood.

Disease development - The disease is favored by cool (12-20°C) humid weather conditions and dense crop canopies where leaves remain wet for prolonged periods.

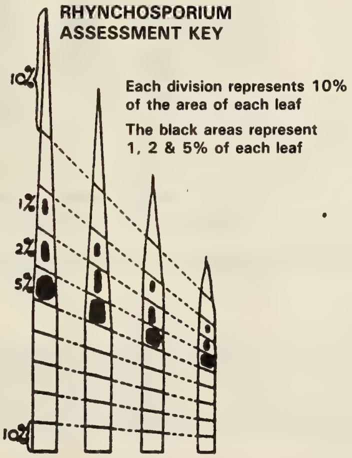
Symptoms - Scald is primarily a foliar disease but is also found on leaf sheaths and glumes. Large water-soaked grey-green spots that rapidly dry out, becoming bleached with brown margins, appear on the leaves. Spots often join up killing the entire leaf.

Detrimental effects - Yield losses in Alberta have been calculated at 2.4 per cent, although losses in particular fields may exceed 25 per cent. Losses are due to a decrease in photosynthetic area on the flag and second leaves resulting in reduced seed weight. Severe scald infections can cause damage resembling black point but the damage is not confined to the embryo end. Foliar diseases of cereals - there is a direct relationship between the amount of disease present on upper leaves and the resulting losses in grain yield. The top two leaves of the cereal plant are responsible for supplying most of the energy required to produce well filled grain. This formula can be used to predict potential yield losses at the milky ripe growth stage. If scald appears on the upper leaves and sheaths in mid-July, anticipate considerable yield loss. If the scald does not show up until early to mid-August, disease levels may be heavy but actual losses from this disease will be considerably reduced since the grains are well filled by this time.

Threshold levels - No data available.

$$\frac{\%\text{ yield loss } = 2/3 \times \%\text{ area of flag leaf infected } + 1/2 \times \%\text{ area of second leaf infected}}{2}$$

Sampling - Examine the crops at the milky ripe stage, (see Feekes scale page), assess no less than 25 main tillers selected at random along each of two diagonals. Assess percentage of first and second leaf affected see figure. Take the average of the first leaf and the second leaf and apply it to the above formula. This will give you a reasonable estimate of expected crop loss due to scald.



Management Strategy - Use resistant varieties and reduce disease levels in the crop residue.

Control Mechanisms

- Turn under or deep till surface barley residue. This reduces disease levels when barley follows barley.
- Seed early with an early maturing variety to miss the major build-up of disease that hits later-sown crops and later maturing varieties.
- Use a crop rotation of at least one year with nonhost crops such as other cereals or canola.
- Use resistant varieties.

SEPTORIA COMPLEX

Speckled leaf blotch - **Leptosphaeria avenaria** f. sp. **triticea** (asexual **Septoria avenae** f. sp. **triticea**)
Glume blotch - **Leptosphaeria nodorum** (asexual **Septoria nodorum**)

Biology - This group of diseases is known as Septoria complex because they all may be present in the same field, even on the same plant. The Septoria complex of diseases occurs mainly on wheat, but is common on barley, oats, rye and grasses, especially **Poa** and **Agrostis** spp. and is widespread throughout the Prairie Provinces.

Disease cycle - The fungi overwinter on stubble, straw, and leaves of winter wheat and on seeds (**S. nodorum** mainly). Spores infect the new crop during wet weather. Secondary infection results from spores produced on infected leaf spots, being transported by splashing rain and wind to nearby plants.

Disease development - Wet windy weather favors disease while dry conditions reduce or prevent new infections and spore producion on diseased plants. For successful spore infection to take place six hours or more of wetness are required. Increases in the incidence of this disease is related to denser, more humid foliage brought on by higher nitrogen inputs.

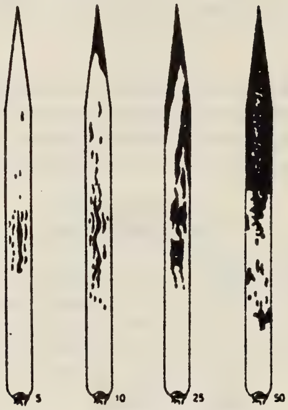
Symptoms - The disease develops on all above-ground plant parts. Yellow flecks generally appear first on lower leaves.

Infections which are initially water soaked become dry, yellow and finally red-brown. Tiny black pepper-like dots (reproductive structures - pycnidia) may appear in the infected areas. **S. nodorum** most often causes blotches on the glumes and stem nodes rather than on the leaves. Infections begin at the glume tips and work downward as purplish areas later forming the dark characteristic pycnidia.

Detrimental effects - Critically reduced photosynthetic activity caused by lesions on the important upper leaves and glumes can result in severely depressed yields. Seed set is not harmed but seed filling is impaired and shrivelled grain may be lost with the chaff at harvest.

Threshold level - No data available.

Sampling - Use the barley scald assessment procedure.



Percentage of leaf area affected

Management Strategy - Create an environment unsuitable for the disease.

Control Mechanisms

- Use crop rotation with noncereal crops.
- Turn under the stubble and crop residue to reduce disease incidence and control volunteer wheat seedlings.
- Use seed grown in the drier areas of the province which may be free of or very low in seed borne infection.
- Do not use stubble mulching and minimum till. These practices increase the incidence of this disease.
- Use wide row spacing and adequate but not excessive nitrogen levels. These practices lower canopy density and humidity that favors infection.
- Use resistant varieties.

TAN SPOT (yellow leaf spot)
Pyrenophora tritici-repentis (asexual - **Drechslera tritici-repentis**)

Biology - Tan spot affects wheat as well as brome and wheat grasses. It occurs in all wheat growing areas of the Prairie Provinces. Rye and barley are rarely affected and oats are resistant.

Disease cycle - The fungus overwinters on crop residue and fall sown wheat. Spores produced in early spring are moved by wind to infect other plants. Spores produced on infected leaves become primary sources of disease spread during prolonged wet periods. Seedlings may become infected but not appear diseased until heading.

Disease development - Spore production and release from crop residue and existing leaf infections are encouraged by rain and dew. For new infections to occur on wheat leaves, a minimum of six hours of wetness is necessary. The presence of leaf infections on the winter wheat in May or on spring sown crops in June could result in a rapid disease build-up if prolonged wet weather conditions occur.

Symptoms - Tan brown flecks first appear on lower leaves. The flecks become lens-shaped, expand and join up. The centres of the spots become dark brown. A zone of bright yellow tissue usually surrounds the dark brown centres. Heavily infected leaves may wither and die. Infected seed is usually smaller and shrivelled and may have a pinkish coloration.

Detrimental effects - Yield reductions result from loss of photosynthetic area, especially if flag leaves and heads are infected. Following high levels of disease, kernel weight may be lighter with a possible down grade for shrivelled and off-color seeds.

Threshold levels - No data available.

Sampling - Use barley scald assessment procedure.

Management Strategy - Reduce disease carryover between seasons.

Control Mechanisms

- Follow a crop rotation with poor hosts such as barley and oats, or nonhost crops like canola, flax, corn, potatoes and alfalfa.
- Turn under wheat residue. This will reduce the amount of surface straw that can produce air-borne spores during the growing season.
- Avoid planting winter wheat on land adjacent to spring wheat that was infested with tan spot.

HEAD DISEASES

COPPER DEFICIENCY (Melanosis)

Biology - Copper deficiencies can occur in the Grey Wooded, peat, sandy and transition soils. They are seen mainly on barley but effect wheat and oats.

Disease cycle - This is a nonparasitic disease.

Disease development - Dependent on the availability of copper.

Symptoms - Copper deficient barley plants develop light green leaves that become dry at the tips. Younger leaves may fail to unroll, or curl and twist or pigtail. Affected roots are stunted and crowns are excessively branched and rosetted. Heads are bleached and may be incompletely emerged or appear normal but fail to set seed.

The heads of copper deficient wheat plants, especially the variety Park, turn brown (melanosis), resulting in heads that produce shrivelled or no seed. The melanosis which occurs is believed to be the result of a secondary bacterial infection.

Detrimental effects - Yield losses result from empty head or poorly filled grains.

Threshold levels - The range between sufficient and deficient levels of copper are quite small but not fully understood. Rye is known to have the ability to take copper from soils where the levels would be considered deficient for wheat or barley.

Sampling - A specific soil test for copper levels can be carried out at a soil testing laboratory.

Management Strategy - Correct deficiency.

Control Mechanisms

- Spray copper sulfate or apply fine crystalline copper sulfate on the soil or copper oxychloride, chelated copper, or copper oxide as a foliar spray at late tillering to reduce the problem. However, application methods have not yet been worked out.
- Grow cereals such as rye that are tolerant of low soil copper levels.
- Neepawa and other wheats may not show melanosis as in the variety Park, but yields can be equally depressed.

	Per cent Disease		Yield (t/ha)	
Wheat cultivar	Without copper	With copper	Without copper	With copper
Park	100	39	0.07	1.64
Neepawa	18	2	0.40	2.13
Sinton	6	0	0.19	1.49
Thatcher	5	0	0.20	1.72
Columbus	10	2	0.26	1.59
Katepwa	19	1	0.23	2.14

Comparisons of six wheat cultivars for per cent disease and grain yield with and without added copper to a Black Chernozemic sandy loam soil in 1985.

ERGOT
Claviceps purpurea

Biology - Ergot infects many cereals and grasses, these include in order of decreasing susceptibility, rye, triticale, wheat and barley. Oats are rarely affected.

Disease cycle - Ergot overwinters as black grain-sized fungal structures. In late spring, these ergots germinate and form tiny spore producing mushrooms. Infectious spores are carried by wind to the host during the flowering stage. Infection of the cereal flowers may produce a secondary phase called honeydew. Honeydew is a dark sticky liquid that contains large numbers of ergot spores which can be spread to adjacent flowers and heads by insects and rain. Early ergot germination in April and May can lead to infection of early flowering weed grasses which produce honeydew at the time of cereal flowering.

Disease development - Cool, damp weather in late spring and early summer favors ergot germination and helps prolong the flowering period of cereals and grasses increasing the possibility of ergot infection.

Symptoms - Ergot is most easily recognized by the hard black ergots which replace the grains of the affected head. Heads may contain one or more ergots. Earlier in the season, before the ergots are produced, an amber liquid or honeydew can be detected on individual flower heads. Heads may appear dirty because of the collection of dust and pollen on the sticky honeydew.

Detrimental effects - Ergot bodies are very poisonous. Alkaloids present in ergot are extremely toxic to humans and livestock. Ergot alkaloids have been detected in flour and cereals intended for human as well as animal feeds. For cattle, 0.5 per cent by weight of ergot in the diet causes reduced feed consumption and weight loss. Economic losses result through reduction of yield (occasional losses of 5 per cent in rye and 10 per cent in wheat have been noted) and through rejection or down grading of contaminated grain at the elevator.

Cereal spikes containing ergot have fewer kernels per head with less weight per seed. Yield loss percentage for rye can be estimated -

$$\% \text{ loss} = \% \text{ ergoty spikes} \times \frac{1 - (\text{seed weight of ergoty spike})}{(\text{seed weight of healthy spike})}$$

Threshold levels
The Canadian Seeds Act (July 1987) defines the maximum number of ergots allowed per kilogram of seed before the sample is downgraded.

Grade name		Max. number ergot/kg	
	Wheat	Barley Oats	Triticale Rye
Canada Foundation #1	1	1	2
#2	8	8	10
Canada Registered #1	1	1	2
#2	8	8	10
Canada Certified #1	1	2	4
#2	8	8	15
Common #1	1	2	4
#2	8	8	15

Sampling - Ergot can move into a field through contaminated seed but usually the source of inoculum is infested headland grasses. When the disease source is the headland grass the highest density of ergoty plants is around the perimeter along the headlands. If the infected plants are more evenly distributed throughout the crop, the disease source is likely from contaminated seed or a previously infected crop. Knowledge of the distribution pattern is important at grain harvest.

Management Strategy - Reduce inoculum level.

Control Mechanisms

- Use resistant varieties.
- Use ergot free seed. Ergot can be removed through seed cleaning operations.
- Use a crop rotation with nonhost crops to reduce inoculum levels. Ergots rarely survive more than a year in the soil.
- Bury crop residue (2.5 cm or more). This will help as spore producing mushrooms cannot emerge above ground.
- Mow headland grasses on a regular annual basis well before seed set. This will prevent ergot production. Meadow foxtail is extremely susceptible to ergot.
- Harvest the headland area swaths separately since they are likely to have the highest degree of ergot contamination.
- Store ergoty grain intended for seed for two years and the ergots will die, but the grain will remain viable for many more years.

FUSARIUM HEAD BLIGHT (Scab, Pink mold, White heads, Tombstone scab)
Gibberella zeae (asexual **Fusarium graminearum**), **F. avenaceum**, **F. culmorum**, **F. poae**

Biology - This disease affects all grain crops, especially those grown in humid areas. The causal fungi may also incite different diseases on other plant parts. Therefore, head blight may appear with root rot or leaf infections or be the precursor of future seedling blight infections. Wheat planted after corn seems to be particularly prone to this problem because of the large quantities of this fungus that can be produced from corn residue.

Disease cycle - The fungus overwinters in crop residue and grasses. Seedlings may become infected at emergence. Spores are first produced on stem infections at the base of the plant. These spores are spread by rain or wind to infect flower parts, glumes or other portions of the head.

Disease development - This fungus is favored by prolonged warm, moist weather.

Symptoms - The disease is most conspicuous on wheat and barley. Head blight is recognized by premature bleaching of one or all of the spikelets in the head. Infected spikelets are often sterile. Infection of the spikelet stalk may result in the seed above the point of infection not filling. Small dark spots and fungus growth with an orange to pinkish tinge may be seen on diseased heads. Infected grain is shrivelled and lighter in weight with individual kernels having white or pinkish coloration.

Detrimental effects - Yields are reduced by floret sterility and poor seed filling. More important however, is the contamination of the grain by mycotoxins. Mycotoxins, such as vomitoxin are highly poisonous, especially to nonruminant animals. Vomitoxin is found mainly in soft white winter wheat grown in the eastern provinces. Wheat is acceptable for human consumption only when it is virtually free of mycotoxins. Mycotoxins reduce quality and marketability. These losses outweigh yield losses. This disease may be more severe on semi-dwarf and durum wheats than on hard red spring types.

Vomitoxin is rarely found in prairie grains. There are no records of this toxin in Alberta cereals even though the scab or head blight phase of this disease is fairly common on some varieties.

Threshold levels - No data available.

Sampling - Undersized cereal grains with distinct pinkish discolorations should be forwarded for laboratory analysis.

Management Strategy - Delay or reduce disease severity.

Control Mechanisms

- Turn under crop residue to reduce inoculum levels.
- Use two to three year crop rotations avoiding cereals and grasses.
- Control barnyard grass and quack grass as they are noncrop hosts.
- Avoid seeding wheat into corn stubble.
- Avoid seeding spring or winter wheat near corn fields infected by Fusarium fungi.
- Plant early maturing cereal varieties which may escape infection.

SMUTS

Covered - barley - **Ustilago hordei**
- oats - **U. kolleri**

False Loose - barley - **U. nigra**
Loose smut - barley - **U. nuda**
- oats - **U. avenae**
- wheat - **U. tritici**

Common bunt (stinking smut) - triticale and wheat - **Tilletia caries, T. foetida**

Stem smut - rye - **Urocystis occulta** - see Stem diseases

Dwarf bunt - winter wheat - **Tilletia controversa** - not known on prairies - see section on Quarantines and Inspections.

Biology - All cereals are attacked by smut but each crop has a species of smut fungi specific to it. Each smut species has a number of races that differ only in their ability to infect certain varieties of that crop host.

Disease cycle - Covered and false loose smut of barley, bunt of wheat and loose and covered smut of oats will be dealt with as a group because of their similar disease cycles. These fungi overwinter as spores on the seed surface. When infested seeds are sown, smut spores germinate, penetrate the seedling and grow within the cereal host until the heads develop. Smut fungi replace all or most of the grain head, forming masses of black smut spores instead of seeds and chaff. These spores are released at grain harvest and contaminate the surface of other healthy kernels.

True loose smut of barley and wheat differs from the above cycle in that the fungi overwinter within the embryo of the seed. The fungus grows within the plant and produces loose black smutted heads. Wind borne dust-like spores infect healthy cereal flowers, where they penetrate the developing seed and infect the germ (embryo).

Disease development - True loose smut infection is favored by cool wet weather in July, which slows down and prolongs the flowering period allowing more time for infection.

All other smuts are favored by seeding into cold soils during the late fall or early spring.

Symptoms - Most smut fungi attack the internal tissues of the grain, replacing it with dark brown or black smut spores.

Covered smut (barley, oats) - The plant may be slightly stunted with hard, compact, upright, smutted heads. The smut balls are covered in a membrane that remains intact along with the awns and chaff.

False loose and true loose smut (barley) - These fungi have a very thin covering membrane around the spore masses. The brown spores are blown or washed away leaving bare spikes in the ripening crop.

Bunt (wheat and triticale) - Infected heads may be wholly or partially smutted. The heads may remain greener longer and glumes in the infected head may be spread apart. Awns may be reduced or fall out as the heads ripen. Bunt balls are rounder than wheat kernels. When these balls are ruptured, the loose black powdery spores have a distinctive fishy odor.

Detrimental effects - Smuts attack the grain directly replacing the contents resulting in a 1:1 direct yield loss. A 10 per cent bunt infection, if the heads are completely infected,results in a 10 per cent yield loss (aside from quality considerations). The presence of covered and false loose smut and bunt also results in a drastic reduction in grain quality because of the visible contamination with black smut spores.

Smutted grain should be stored separately from clean grain. Heavily smutted or bunted grain will not be accepted at the elevator and may even be difficult to sell as feed (owing to respiratory or feeding problems that might result in livestock).

Losses from loose smut in barley average less than 1 per cent, but losses of up to 40 per cent have been recorded.

Threshold levels - These levels are from the Canadian Seeds Act, July 1, 1987.

Grade		Max % of smutty kernels (barley)
Canada Foundation	#1	2
	#2	4
Registered	#1	2
	#2	4
Certified	#1	2
	#2	4
Common	#1	4
	#2	6

The fishy odor from bunted wheat is detectable at less than .01 per cent seed infection.

Sampling - The following formula can be used to calculate losses caused by loose smut and bunt in barley wheat and oats. The percentage of infected ears is directly proportional to grain yield loss.

$$\text{Loss (kg/ha)} = \frac{Pr}{100\text{-}Pr} \times Pa$$

Pr = percentage infected ears
Pa = actual yield (kg/ha)

This is done during heading (Feekes G.S. 10.1-10.5) for true loose smut and during ripening (Feekes G.S. 11) for bunt. Fifty plants along a diagonal are assessed at a site selected at random. The percentage of infected ears is calculated. Thus a 10 per cent infection in a 3000 kg/ha crop $= \frac{10}{100\text{-}10} \times 3000 = 334$ kg/ha yield loss.

Management Strategy - Resistance and avoiding spores.

Control Mechanisms

- Use resistant varieties.
- Use smut free seed.
- In southern Alberta bunt of wheat may be soil borne. Avoid cropping continuously to winter wheat and do not seed winter wheat within 2 km of a known bunt infected field of either spring or winter wheat since the spores are wind blown.
- Use a hot water seed treatment for loose smut. Dip seeds in 20 °C water for 5 hours, drain them dip in 49 °C water for 1 minute, then 52 °C water for exactly 11 minutes, then immediately in cold water until seeds cool off. Some seed may be killed by hot water treatment.

VIRAL DISEASES

ASTER YELLOWS

A mycoplasma-like organism (MLO)

Biology - This virus-like disease can attack barley, and numerous other noncereal crops. The MLO is transmitted by a leafhopper vector **(Macrosteles fascifrons)**. Aster yellows has not been shown to occur naturally in field grown oats or wheat but the MLO has been transmitted experimentally by leafhoppers. There may be some confusion between the symptoms of aster yellows and barley yellow dwarf.

Disease cycle - Each spring, inoculum is brought into western Canada by infective leaf hoppers which migrate in from the United States. Barley may also become infected by leafhoppers that overwinter locally and acquire the MLO from infected perennial weeds.

When the leafhopper feeds on an infected plant, MLOs are taken up by the insect vector. After 8-10 days, the leafhopper becomes infectious and is capable of transmitting this organism to healthy plants for the remainder of its lifespan.

Symptoms - Chlorotic blotches appear on the older leaves, and leaf margins of younger leaves curl under. Blotches coalesce and the entire leaf becomes chlorotic. Plants appear dwarfed and bushy because of shortened internodes. Heads of infected plants may have distorted awns or floral parts resembling leaves.

Detrimental effects - Reduced photosynthetic area plus head sterility causes yield reductions. Severity of this disease varies from year to year depending on the size of the population of migrating leafhoppers. The disease is cyclical and only occasionally is of economic significance on barley.

Threshold level - No data available.

Sampling - To positively diagnose this disease a complex procedure involving leafhopper vectors and electron microscopy must be used.

Management Strategy - Minimize the extent of infection.

Control Mechanism

- Seed your crops early. This allows the crop to mature to a stage where the MLO can cause little damage.

BARLEY STRIPE MOSAIC

Barley stripe mosaic virus (BSMV)

Biology - Stripe mosaic is a seed-borne virus. In Canada, the virus has occasionally been detected in pedigree seed but losses caused by BSMV have been rare in recent years. Barley is the main host but on rare occasions it has been found in wheat and several grass species.

Disease cycle - The virus is seed-borne and is transferred from plant to plant when crop leaves rub against one another. Infected seeds produce infected plants. Seed from infected plants is generally infected to a 60 per cent level.

Disease development - Disease builds up when there is repeated planting of infected seed.

Symptoms - These may vary with the virulence of the BSMV strain and time of infection. Infections appear as chlorotic mottling with spots or stripes of a yellowish color. Infected plants may be stunted and later maturing than healthy plants.

Detrimental effects - Yield losses are proportional to the level of infection in the seed lot. Losses are caused by reduced grain production, fewer heads per plant, semi-sterility and incomplete head emergence from the sheath. Heavily infected crops have had yield reductions of up to 25 per cent.

The percentage of infested seedlings indicates the level of grain infection.

Threshold level - No data available.

Sampling - For a positive identification of the disease send a sample to your nearest plant disease laboratory.

Management Strategy - Avoid introducing the disease.

Control Mechanisms

- Use virus free seed.
- Control volunteer barley. Do not plant barley after barley if the previous barley crop was infested.

BARLEY YELLOW DWARF
Barley, yellow dwarf virus - Oats (Red leaf)

Biology - The barley yellow dwarf virus can infect barley, oats, rye and wheat as well as numerous species of grasses. It has been recorded in most parts of the world and is considered the most common virus disease of cereal crops. BYDV is transmitted by several species of aphids and occurs in many strains or types.

Disease cycle - Since the aphid vectors cannot overwinter in Alberta, they must be blown in every year from the United States. These aphids may already be infective but can also pick up the virus here from perennial native grasses. As the aphids (winged or wingless) feed on the cereal crop, they transmit the virus through their mouth parts. The aphids can remain infectious for life (around 40 days).

Symptoms - These vary with the host species and the stage of crop development. Infections at the seedling stage may result in death or dwarfing as well as sterile heads.

Leaves turn yellow from the tip down along the leaf margins or in blotchy patches. Infected barley leaves, particularly flag leaves, turn bright yellow; in oats, the leaves maybe turn red to purple. Discolored areas enlarge and progress to the base of the plant. Heads may be wholly or partially sterile. There may also be an increase or decrease of tillers produced by infected plants. Cereal plants infected early in the season may be shaded out by healthy or late infected surrounding plants.

Recently in southern Alberta barley plants have appeared yellowed and stunted with virus-like symptoms correlated with the presence of small brown mites. Whether this is a new virus disease and there is a link between the brown mite and these symptoms is being researched.

Detrimental effects - BYDV affects yields by causing stunting, reduced tillering, sterility, and failure to fill kernels.

In some regions in the United States, yield losses of 30-50 per cent in oats and 5-30 per cent for barley and wheat crops have been reported.

However, since the aphids must blow in from the United States, they generally arrive too late in the season to cause significant yield loss. On the Prairies, the only crops which are damaged significantly are late sown spring and early sown fall seeded crops.

Bright yellow flag leaves in barley by late June or early July will indicate little or no yield contribution from those plants. Severe stunting in winter wheat by mid-May could indicate crop failure.

Threshold levels - No data available.

Sampling - Confirmation of this disease can only be done at a laboratory.

Management Strategy - Avoid aphid vectors.

Control Mechanisms

- Use resistant varieties.
- Seed early in the spring. This will allow the maximum growth before possible infection by migrating aphids.

BLUE DWARF OF CEREALS, CRINKLE OF FLAX
Oat blue dwarf virus (OBDV)

Biology - Oat blue dwarf virus can affect barley, flax and oats.

Disease cycle - The virus can only be transmitted by the six spotted leafhopper **(Macrosteles fascifrons)**, which does not usually overwinter in Canada. Each year infective leafhoppers must be blown in from the United States.

Disease development - Severe outbreaks occur following weather which brings winds that carry virus infected leafhoppers into the prairie provinces early in the spring.

Symptoms - On oats: Early spring infection results in severe stunting. Plants are dark blue green with short rigid leaves standing out at right angles. Heads are usually blasted and infected plants may produce new tillers.

On barley: Symptoms are generally similar to oats except that barley plants do not produce new tillers.

On flax: In flax, this disease is called crinkle. It results in stunting and reduced tillering.

Detrimental effects - Reduced tillering and blasted heads result in yield loss. Mild or suppressed symptoms on many hosts make field diagnosis difficult, therefore OBDV may cause significantly more damage than realized.

Threshold levels - Blue dwarf is not usually of significant economic importance in the Prairie Provinces.

Control Mechanism

See general viral disease control later in the text.

WHEAT STREAK MOSAIC
Wheat streak mosaic virus (WSMV)

Biology - Wheat streak mosaic virus attacks barley, corn and some grasses, but is most common on winter and spring wheats. Oats and rye may be infected but they do not appear to be seriously damaged. Mites that transmit this disease overwinter on winter wheat and occasionally fall rye.

Disease cycle - Wheat streak mosaic virus is transmitted by the microscopic wheat curl mite **(Aceria tulipae)**, and mechanically through leaf rubbing. The mite, a relative of the spider mite is small, white and cigar-shaped with four sets of legs near the head. It has no wings and is so tiny that it can be blown from field to field by wind. Both the mite and virus cannot survive without living host plants.

Winter wheat carries both the mite and virus over winter. In spring, mites multiply rapidly and are blown to other plants. These may be crops of spring wheat or volunteer spring wheat, which then harbor the mite and virus over the summer. If winter wheat is sown near to unharvested spring wheat, infective mites can be blown onto winter wheat completing the disease cycle.

Disease development - Development of this disease depends on the population of mites, the presence of virus infected wheat plants and sufficient moisture for good plant growth and rapid mite reproduction. Severe outbreaks occur when there is a buildup of mites and virus on volunteer spring wheats in fields next to early planted winter wheat. Symptoms of the disease become more pronounced when temperatures climb above 10 °C in the spring.

Symptoms - Usually first appear at the edges of fields and under favorable conditions move throughout the field.

Winter wheat, although infected in the fall, rarely shows symptoms until spring. These appear on the leaves as dashes, streaks or yellow stripes parallel to the veins. Leaves become more and more mottled until the green areas disappear and the plant dies. Infected plants are stunted, the degree of stunting depends on how early infection took place. Another similar mite-spread virus with a comparable life cycle called wheat spot mosaic virus may sometimes be present in winter wheat.

Detrimental effects - Wheat infected in the fall or at an early tillering stage stops growing and few to no heads are produced. Infection at late tillering to early jointing stage results in head formation but flowers may be sterile. With late season infection during jointing to boot, the flowers are fertile but the resulting grains are reduced in size.

Fall infected plants do not produce grain the following season. One study found that stunted diseased plants yielded 78 per cent less than healthy plants, and seed milling quality is reduced substantially.

Threshold levels - No data available.

Sampling - Mites in large populations on wheat will cause the leaf blades to curl upward and inward. Tips of new leaves are often caught in the curled leaf above it; this may indicate the presence of the mites and virus. A microscope or a good magnifying glass is necessary in order to see the mites.

Management Strategy - Break the life cycle of the wheat curl mite by preventing infection of winter wheat.

Control Mechanisms

- Avoid sowing winter wheat near immature spring wheat or other cereals. Seed after spring crops mature.
- Control all volunteer host plants at least two weeks before winter wheat is planted, this includes adjacent fields. The mites cannot survive longer than 10 days in the absence of living cereal plants.
- Plant winter wheat as late in August or September as feasible to avoid the active period of the mites moving from growing spring cereals.
- Avoid planting spring cereals, particularly wheat next to infected winter wheat.
- Control volunteer winter wheat two weeks before spring cereals are sown.
- Do not reseed a severely diseased winter wheat field with spring wheat because of the difficulty of completely eliminating all diseased winter wheat plants.

GENERAL CONTROL MEASURES FOR VIRUSES

- Remove the infection source. Control volunteers and alternate hosts such as annual or perennial weeds and headlands grasses.
- Use virus-free seed for the control of barley stripe mosaic virus. No other viruses or mycoplasmas are known to be seed-borne in prairie cereals.
- Modify planting and harvesting procedures.
  - Break the infection cycle. Avoid overlap between spring and winter wheat. This breaks the cycle of the wheat streak mosaic virus.
  - Change planting dates. The earlier the infection the greater the yield reduction. Older plants may be more resistant to infection and virus diseases develop more slowly. The best time to plant will depend on the time of migration of the vector. For late migrations, which is usually the case on the prairies, early seeding is advised.

- Reduce plant spacing. Closer plant spacings tend to reduce infections. Use a planting rate that will provid complete ground cover without reducing yield through competition. Aphids are attracted by yellow and we spaced plants that have open growth habits that expose young yellowish leaves.

- Control vectors with:
  - Insecticides
  - Neutral oil sprays to make plant surfaces unattractive to insect vectors
  - Non-chemical barriers against infection such as tall cover crops of sunflowers.
- Use immune, resistant or tolerant varieties.
- Prevent long distance spread through quarantine and inspection.

DISEASES OF OILSEEDS

(Canola, Flax, Mustard, Rapeseed, Sunflower)

SEEDLING AND ROOT DISEASES

SEED DECAY, SEEDLING BLIGHT, DAMPING-OFF AND ROOT ROT (ROOT ROT, BASAL STEM ROT)

Rhizoctonia solani, Pythium spp., Fusarium spp.

Pythium spp., Fusarium spp.

Biology - Damping-off is a collective term used to describe seed decays and seedling blights. There can be pre-emergence seed decay when the seedling never emerges or postemergence seedling blight or damping-off when seedlings die soon after emergence. Because of delicate seed coats which may be cracked during harvest, seedling blight is often a problem in flax, canola, rape and mustard. Canola seedlings as well as rape and mustard seedlings may be severely affected by seedling blights if planted into cold dry soils extra early in the season.

Disease cycle - Fungi can attack damaged or healthy seeds as soon as they absorb water before germination. Infected seeds may die before they emerge. Plants that are affected by disease after germination may die or grow with less vigor and yield than healthy plants.

Disease development - Conditions required for seedling blight depend on the pathogen present. Cold damp soils favor **Fusarium** species while loose, cold, dry well-worked soils favor **Rhizoctonia solani**, and wet heavy soils favor **Pythium** species. **Rhizoctonia solani** is the causal fungus in most disease problems of seedling canola and flax.

Symptoms - Patchy emergence is usually the first symptom of seedling blight. Affected seeds may fail to germinate and rot or germinate but fail to reach the surface because of fungal disease. After germination and emergence, seedlings may appear to stagnate and "disappear" under dry windy conditions. Examination of these seedlings will show a girdling of the seedling stem at or just below the soil surface.

Mature plants may also be attacked by these fungal pathogens. The resulting disease may be root rot caused by **Rhizoctonia solani** or foot rot by **Fusarium** species or occasionally a damping-off caused by **Pythium** species. Infected areas on the lower stems, typical of **Fusarium** infection may be sunken and black bordered, containing pink colored spores during wet conditions.

Detrimental effects - Direct yield losses occur as a result of loss of plants at the seedling stage. Surviving diseased plants may produce less seed or die before the seed is ripe. On severely infested land, seedling blight may result in a 100 per cent loss of stand.

If seedling losses are uniform throughout the stand, surviving canola plants will compensate by growing larger. If the loss is patchy and large areas die out, then compensation cannot take place and yield losses result. Weed infestations also take over on these bare patches of soil.

Threshold levels - No data available.

Sampling - Unless soil conditions are unusually dry, uniform seedling emergence should have taken place around seven days after planting. Check the stand every few days for seedling blight and possible flea beetle damage.

Management Strategy - Use a crop rotation and provide conditions unfavorable for infection.

Control Mechanism

- Seed shallowly (2 cm or 1/2 inch) into warm moist soil when possible.
- Sow high germination seed into a firm seedbed, packing the soil to bring the moisture up around the seed.
- Maintain soil fertility. Inadequate or unbalanced nutrition favors seedling blight. Fertilizer placed with seed may reduce or delay emergence, no more than 9 lb N or 18 lb P_2O_5/ha should be placed with the seed.
- Minimum soil temperatures at the 5 cm level (2 in.) for seeding should be 3-5 °C for Argentine or 5-8 °C for Polish types.
- Use a crop rotation. Avoid canola after canola. Flax should follow another crop rather than summerfallow. Avoid legumes and sugar beets in flax rotations as they are susceptible to the same **Rhizoctonia** strains.
- Control volunteer flax, canola and cruciferous weeds.
- Adjust your combine settings. Proper combine setting helps prevent cracking of seed coats which favors increased seedling disease problems.
- Treating canola seed with strains of **Bacillus** species for control of seedling blight under Alberta conditions has been shown to be ineffective (no better than the untreated check).
- If seedling blight damage is extensive and patchy, consider reseeding if the soil has warmed up and remained moist, or rotate to a cereal crop.

CLUBROOT OF CRUCIFERS
Plasmodiophora brassica

Biology - Clubroot affects all members of the (cabbage) crucifer family. It has not yet become a concern in canola growing areas of the Prairie Provinces, but is a problem in areas of southern British Columbia and eastern Canada.

Disease cycle - Resting spores of this fungus can survive in the soil for five or more years. These resting spores germinate in the presence of host roots to produce tiny mobile spores that can swim in the soil moisture. These spores enter the rootlets and multiply in the host cells. Infection causes the roots to produce galls or clubs characteristic of this disease. Resting spores formed in these clubs are released into the soil when the roots rot away. The disease organism exists in a large number of strains that vary in their ability to attack the various species of the crucifer family.

Disease development - In order for resting spore to germinate, the soil pH must be below 7.2 and soil moisture must be 50 per cent above water holding capacity.

Symptoms - Infected roots produce galls ranging in size from tiny nodules to large club root overgrowths that may involve the entire root system. Galls first appear white and firm but become soft and brown as they mature and rot. Aboveground symptoms are wilting during warm weather and stunting of affected plants.

Detrimental effects - Diseased roots are unable to transport food and water and rotting galls (clubs) allow other root rotting organisms to infect the root system.

The potential for damage to Polish canola is high, particularly in acidic soils.

Threshold levels - No data available.

Sampling - The clubroot disease organism has been found in a few locations on the prairies in horticultural (backyard) crops (cauliflower, cabbage).

Management Strategy - Avoid introducing the disease organism.

Control Mechanisms

- Seed into soil free of the clubroot organism.
- Do not use machinery from infested fields since resting spores can be carried in soil.
- Do not allow irrigation or drainage from infested fields to contaminate clean areas.
- The clubroot organism can survive passage through digestive tracts of farm animals. Feeding clubroot infested turnips to cattle can result in spread of the organism through manure.
- Use resistant varieties. The clubroot organism exists in a large number of strains some of which may or may not attack canola varieties. For example, the Polish variety Candle has been known to be highly susceptible to race 6 of the clubroot organism, whereas Altex, an Argentine variety, was relatively immune.
- Use a long crop rotation with noncruciferous crops (seven years) as spores can survive for a considerable time.
- Control cruciferous weeds in the rotation.
- Provide drainage to reduce soil moisture. Wet soils favor the clubroot disease.
- Provide adequate nutrient levels. Crops are less susceptable to clubroot damage if they are growing vigorously.
- Lime the soil. Raise the soil pH above 7.2 if feasible.

ROOT ROT (brown girdling root rot, root rot complex)
Rhizoctonia solani

Biology - Brown girdling root rot is quite different from blackleg and other stem and root rots of canola because it remains confined to the roots and does not appear above the soil line.

Disease cycle - **Rhizoctonia** is a soil-borne organism. When canola roots come into contact with this fungus, it grows into the root. Following infection, the fungus may grow slowly in the roots. When conditions are favorable disease symptoms typical of root rot appear. This fungus can infect canola roots at any growth stage. When seedlings are attacked and die-off, the disease is called seedling blight. In the fall, overwintering bodies are formed in the soil and continue the cycle in subsequent years. There are many documented strains of the **R. solani** fungus that vary in the degree of aggressiveness shown when attacking canola plants.

Disease development - High soil moisture, fine-textured soils with a high clay content and high copper levels (4-20 ppm) and poor or unbalanced fertility favor this disease.

Symptoms - Wilting or lodging occur on the aboveground plant parts. Light brown areas may appear on any part of the root. These areas may expand and girdle the root, becoming dark brown and sunken and rotting the tap root away. Plants may fall over or remain standing, wilt, dry up and die.

Detrimental effects - Direct yield loss is proportional to the amount of root system lost by girdling. Losses result from increased pod sterility, reduced seed weight, seed shrivelling and plant death. There is also an indirect loss from shattering caused by premature ripening, and an increase in senescence-type diseases such as grey-stem. Yield losses of up to 55 per cent in individual fields have been recorded, although the averages range from 8-18 per cent depending on the season.

Threshold Levels - no data available.

Sampling - At midflowering stage, dig up 10 plants from each of 10 spots (100 plants). Wash the collected roots and examine for brown lesions. If only root stubs are present or the tap roots are girdled by brown lesions, the disease will result inconsiderable yield loss. If brown spots are present, but do not girdle the root, actual disease losses may be minimal.

Management Strategy - Maintain conditions unfavorable to the disease-causing fungus, use resistant cultivars and avoid disease build-up.

Control Mechanism

- Use Argentine canola **(Brassica napus)** varieties (Altex, Andor, Regent, Westar) where the growing season allows since they are much less susceptible to this disease.
- Avoid planting canola into heavy clay soils if feasible.
- Maintain recommended N, P and S fertility levels in the soil. The addition of lime will reduce soil copper availability levels which may be a factor in this disease.
- Follow a crop rotation of three to four years using cereal crops. Avoid canola after canola or canola after fescue. Decomposing fescue sod, for reasons not clear, is conducive to the development of this disease.
- Control volunteer canola and cruciferous weeds especially stinkweed, shepherd's purse and ball mustard, all of which can serve as hosts for the fungus.
- Seed shallow and planting into warm moist soil. This may reduce seedling blight and root rot.

BLACKLEG (canker, dry rot)
Leptosphaeria maculans (asexual - **Phoma lingam**)

Biology - Blackleg can cause considerable yield losses in canola. The disease organism occurs worldwide on plants of the cabbage (crucifer) family. Common crop plants and weeds attacked by this fungus include cabbage, cauliflower, mustard, stinkweed, canola, wild mustard and rutabaga.

The blackleg fungus exists in a large number of strains, variations or varieties, like the cabbage family that it attacks. There are mild and severe strains of the fungus and strains that can only attack certain members of the crucifer family.

Long distance spread of the disease on the prairies is believed to have occurred through the movement of infected seed from one area to another. Researchers from Agriculture Canada, Saskatoon demonstrated in 1976 and 1977 that 2 per cent of canola seed samples collected in Saskatchewan were infected with the virulent blackleg fungus. Most infected seed samples had less than 1 per cent of the seeds carrying the blackleg fungus, but there were occasional samples with more than 2 per cent infected seed. Obviously, for the seeds to pick up infection they must have been harvested from fields heavily infected with blackleg and the fungus would have to infect the seed pods in order to infect the seeds. No seed fields with the virulent blackleg disease have ever been identified in Alberta.

Disease cycle - This fungus overwinters on the canola and cruciferous weed residue, and on infected seed. In eastern Canada, the fungus overwinters on winter rape. During wet weather in the spring, the blackleg fungus on the crop residu forms new spore producing structures (fruiting bodies) similar to the pepper-like spots produced during the summer on infected plants. These tiny spots on the old canola cankers discharge thousands of infectious spores into the air from May until October. The spores can travel several miles in the air before landing. Canola residue, particularly larger stems, can resist breakdown for two or more years, and up to four years in a series of dry seasons. Thus infected dead stems can continue to produce spores of the blackleg fungus until they are buried or broken down in the soil. Heaviest spore production comes from two-year-old infected crop residue.

Disease development - Moist weather favors rapid spread of disease, while warm dry conditions halt disease development.

Symptoms - When blackleg infected seed is sown, it is highly probable that the emerging seedling will be infected. Infection, whether from the seed or infested crop residue, can quickly form fruiting structures called pycnidia which look like tiny pepper spots on the infected area. These pycnidia ooze out masses of tine infectious summer spores called pycnidiospores. These spores can be splashed by rain or moved by wind to nearby healthy seedlings. In a single season, one infected seed could spread the infection to as many as 30 or more plants. A crop planted with a trace level of infected seed could have these small areas of infection all over the field. Plants can develop infected areas on leaves, stems and flowering parts. On the stems, the infected areas develop into cankers surrounded by a blackish margin, hence the name blackleg. Blackleg cankers on stems can be up to several inches in length and may girdle the stem. Stem cankers covered with the pepper-like spore producing bodies of the fungus can weaken the plant, causing it to lodge. If the stem is girdled by the blackleg canker, the canola plant may prematurely ripen even if lodging does not take place.

Detrimental effects - The avirulent strain does minimal damage to the crop, rarely causing even 1-2 per cent yield loss. The virulent strain however can cause considerable premature ripening, shattering, lodging and death. In 1985, Saskatchewan reported and estimated yield loss of 5 per cent on 3 million acres. Almost half the fields had average yield losses of 12.2 per cent. In scattered areas, 100 per cent infected fields with 50 per cent yield losses were recorded.

Threshold levels - Having a seed field infected with blackleg is especially undesirable. Blackleg may be borne in or on the seed and purchase of seed with even a low percentage of infected seed is not recommended.

Sampling - Blackleg is most easily detected right after swathing. The black stem cankers stand out sharply against the freshly cut stubble.

At flowering select 20 equally spaced spots in a diagonal line across the field. Pull all plants in a 1 foot circle, count all plants - count the number with severly or slightly cankered stem bases. Divide this number by the total number of plants pulled and multiply by 100. Use the following formula to determine the degree of severity of stem canker (SSC).

$$SSC = \frac{\text{No. of cankered stems}}{\text{total No. of stems}} \times 100$$

Do this again at harvest time, but only count the number of severly cankered stems. Divide it by the total number of stems and multiply by 100.

Use the following table to estimate maximum yield.

Maximum crop yield at various levels of blackleg			
Severity of stem canker		Estimated yield	
At flowering	At harvest	kg/ha	(bu/ac)
More than 90	More than 80	Less than 750	(13.4)
About 60	About 50	About 1250	(22.3)
Less than 40	Less than 30	1500 to 2250	(26.7-40.1)

Another method of assessing yield loss caused by blackleg only uses two ratings, healthy or slightly cankered and severely cankered. The percentage of severely cankered plants, sampled at harvest, is calculated and used as a rating of blackleg severity. Yield losses are assessed by collecting 50 plants from each of the two disease classes and weighing the seed in each sample. Percentage yield loss caused by blackleg is obtained using the formula:

$$\text{yield loss (\%)} = 100 - \frac{100W}{NW_1},$$

W is the total weight of seed from the two samples, W_1 is the average weight of seed per plant from the healthy sample, and N is the total number of plants in the sample.

This formula was developed by D.C. McGee, at the Department of Agriculture, Victorian Crops Research Institute, Victoria, Australia.

Management Strategy - Prevent the introduction of disease to uninfested areas and reduce inoculum levels where the disease is present.

Control Mechanisms

- Follow a crop rotation with nonhost crops. Canola should be planted on canola stubble or near fields that had infected crops in the last three years. In the drier areas of the prairies follow a four or five year rotation.
- Control volunteer canola and cruciferous weeds in the rotation.
- Purchase seed from known blackleg-free areas.
- Hot water immersion treatment for seed (50 °C for 20 minutes) can be used, but it is not fully effective in eliminating the seed borne blackleg organism.

FROST AND HEAT CANKER
Temperature stress

Biology - Heat and frost canker occurs under excessive high or low temperatures at the soil surface. The seedling is injured when young plant tissue comes into contact with soil or air at these temperature extremes. In cereals, this is called heat or frost banding.

Disease cycle - A nonparasitic disease.

Symptoms - In young plants, stems become constricted at soil level, collapse or break-off. In older plants, a canker is formed, which breaks when the standing crop is exposed to strong winds.

Detrimental effects - Direct loss of yield occurs as a result of the death of plants. Damage may be confined to small patches or a few throughout the field, but losses up to 50 per cent have occurred. Damage is usually most severe in thin stands on light soils.

Threshold levels - No data available.

Sampling - Check for damage during periods of weather extremes.

Management Strategy - Avoid heat stress and prepare plants for stress.

Control Mechanism

- Sow early in a north-south direction at a high rate. This reduces heat canker by providing maximum shade for each plant.
- Provide a proper seedbed. This will prevent damage by heat and frost canker by promoting even and vigorous stands that can better withstand temperature extremes.

GRAY STEM (white leaf spot)
Pseudocercosporella capsellae

Biology - This disease is found in all canola-growing areas of the Prairie Provinces. It is usually most conspicuous just before and after swathing, but causes little yield loss.

Disease cycle - This fungus overwinters as mycelium in the canola residue. In the spring, spores are produced with infect canola plants and white leaf spots are formed. The disease generally spreads rapidly after the canola seed is fully developed and the crop has reached maturity.

Disease development - Plants under stress from drought, low fertility, or competition by weeds are more likely to be more adversely affected by this disease.

Symptoms - In the summer, white leaf spots appear on the leaves. Later as plants mature, gray to purple speckled patches appear on the stems and pods.

Detrimental effects - Because this disease affects plants as they are maturing, little significant yield loss results.

Thresholds levels - No data available.

Sampling - Conspicuous after swathing.

Management Strategy - Reduce inoculum levels.

Control Mechanism

- Use crop rotation with nonhost crops.
- Control volunteer canola and related crucifers
- Use good crop production techniques that reduce plant stress.
- Argentine (**Brassica napus**) varieties are less affected than Polish (**B. campestris**) varieties.

FUSARIUM WILT
Fusarium oxysporum f. sp. **lini**

Disease cycle - **Fusarium oxysporium** is both seed and soil-borne. It lives on flax residue but both the fungi and spores can survive a number of years in the absence of flax. The fungus invades the plant roots and causes wilting.

Disease development - Infection may occur in cool soils but warm soils are favored for disease development.

Symptoms - Seedlings may die before or shortly after emergence and older plants may stop growing at any stage of development. Later infections cause yellowing, wilting of leaves and stems, then browning and death. Diseased roots turn ashy grey. Wilted stems often curve downward in a shepherd's-crook shape. Affected plants commonly occur in patches in the field.

Detrimental effects - Direct yield losses result through death of plants.

For many years, flax was only grown on newly broken land because yields were greatly reduced in soils that wer cropped repeatedly, becoming "flax sick". This disease commonly occurs every year now but results in little damage owing to resistant varieties.

Threshold levels - No data available.

Sampling - No procedure.

Management Strategy - Use resistant varieties and prevent disease buildup.

Control Mechanisms

- Use reistant cultivars.
- Follow a crop rotation with a three years with cereals, canola or grasses.
- The fungus may be spread from field to field by wind blown soil, irrigation water or run-off.
- Use disease free seed.

PASMO
Septoria linicola

Biology - Pasmo attacks all the above ground parts of flax.

Disease cycle - This fungus overwinters on diseased flax residue. Infested seeds, chaff and residue can be mixed together in a seed lot. Spores are spread to growing plants by wind and rain. Under suitable moist weather conditions, disease spread is extremely rapid.

Disease development - The disease is favored by warm moist conditions.

Symptoms - Symptoms first appear as brown spots upon the leaves. As the disease progresses, infected leaves may drop off. Brown spots appear at the leaf-stem joints. These spots eventually circle the stem, giving rise to a mottled appearance of alternating bands of brown and green. Flax flowers and bolls may be blighted or discolored.

Detrimental effects - Early infections can greatly reduce yield and quality of seed and fibre. Premature ripening and poorly filled seed result from early infections. Heavy losses may result if the crop is left to be straight combined, and strong winds and heavy rains cause bolls to break off.

In Alberta, this disease usually occurs late in the season, resulting in light damage to the crop.

Threshold levels - No data available.

Sampling - No procedure.

Management Strategy - Reduce carryover inoculum.

Control Mechanisms

- Use crop rotation. Flax crops should be spaced several years apart. Do not plant near fields previously seeded to flax.
- Use clean seed. Clean out any crop residue from the seed that might be infected.
- Plant early in order to escape disease buildup before crop maturity.

SCLEROTINIA DISEASES

Sclerotinia sclerotiorum (syn. Whetzelinia sclerotiorum),

Canola - Stem rot (sclerotinia stem rot, white stem rot).

Sunflower - Sclerotinia wilt (basal stem rot, root rot), and head rot

Biology - These very different diseases are caused by the same fungus. Wilt in sunflowers is caused by below ground root infection by the fungus, while stem rot of canola and head rot of sunflowers result from air-borne spores. This fungus can attack a very wide range of broad leaved plants including many crops and common weeds.

Disease cycle - Although the fungus is the same, the disease cycles for canola and sunflowers are quite different.

Canola: The fungus overwinters as sclerotes, which are hard black structures that germinate in early summer and produce small spore producing mushrooms (apothecia). Minute infectious spores are produced in huge numbers and some land on stems and leaves of the flowering canola crop. Flower petals are necessary as a food source for these spores to grow after germination. Mid to late flowering, when large quantities of fallen petals are present, is the most critical stage for infection of canola plants. After growing on the petal the fungus appears to aquire enough energy or ability to attack living canola plant leaves or stems resulting in typical white stem rot infection. In severe disease outbreaks, the seed pods may be infected. Later, hard black sclerotes are produced inside (sometimes outside) the diseased stems and pods. These are released at harvest to infest harvested seed or contaminate the soil. The soil borne sclerotes may survive for many years before suitable conditions allow them to germinate and form mushrooms and continue the life cycle of this fungal disease.

Sunflower: Plants are mainly infected by mycelium that grows directly from buried sclerotes into the roots. Infected plants wilt and die. Sclerotes are produced in or on the diseased stems and roots. Head rot results from infection by air-borne spores similar to stem rot of canola. Root infection does not take place in canola, oilseed, rape or mustard despite the fact that sclerotes can germinate freely in the soil to form mycelium rather than spore producing mushrooms.

Other oilseed crops: Under some circumstances this fungus will infect and damage flax and safflower in much the same way that canola and sunflowers are attacked.

Disease development - Warm moist soil conditions are required for sclerotes to germinate and form the spore producing mushroom. Mushrooms can be produced by sclerotes present at the soil surface or buried as deep as 7 cm (3 in.) in the soil. Humid weather or heavy dews are required for spore infection during crop flowering. Heavy yielding canola crops with dense canopies that maintain humid air conditions are most likely to become infected with this disease. Under drier conditions, where the absence of surface moisture makes it unsuitable for sclerotial spore production, root infection will show up in sunflowers. Root infection causing sunflower wilt can show up much earlier in the season than aerial spore infection of canola.

Symptoms - Canola: Infections begin as soft watery rots on leaves and stems, especially at the leaf axils. When the rot girdles the stem, the plant dies. The dried infected areas often have zonate markings. Diseased plants become straw colored and later on the stems bleach white and shred. Generally the fungus produces the typical hard black sclerotia in the hollow centres of diseased stems.

Sunflower wilt: This disease can spread along the row by plant to plant root contact. Leaves of infected plants wilt within a few days. Root systems rot and the lower stem develops a wet canker covered with white fungus. Stems become shredded and straw-like. Sclerotes are produced on the inside and outside of the infected area. Head rot: Rotting starts as a light brown, watersoaked area on the outside of a developing flower head. The rot may partially or completely destroy the head. White fungus and sclerotes are usually abundant. In severe cases, the head rots and falls leaving the straw colored stem standing.

Detrimental effects - Canola: Severe losses result when weather conditions suitable for infection occur at midflowering. These losses range up to 50 per cent or more. Yield losses can be attributed to smaller and fewer seeds, premature ripening, shattered pods and the loss of smaller, shrunken seeds during combining. The presence of fungal sclerotes in the combined seed is also undesirable. Some countries have a zero tolerance for the presence of sclerotes in imported grain.

Yield losses equal about 50 per cent of the main stem infections. A field with a 50 per cent main stem infection would have an approximate yield loss of 25 per cent: $50 \times 0.50 = 25$. The actual yield losses depend on the variety, weather and time of infection.

Sunflower: Yield loss is directly associated with the death of plants; a reduction in seed quality and contamination with sclerotes also occurs.

Threshold levels - A grower intending to use a fungicidal spray for disease control would have to gain in the range of four bushels yield to recover the cost of a single application. This will vary with the cost of the chemical, its application and the value of the crop.

These levels were obtained from the Canada Seeds Act July 1, 1987.

Grade		Max % of sclerotes/kg	
		Canola	Sunflower
Canada Foundation	#1	1	1
	#2	2	8
Registered	#1	1	1
	#2	2	8
Certified	#1	1	1
	#2	2	8
Common	#1	2	4
	#2	-	8

Disease Control

Sampling - Sclerotinia Forecast Check List

SCLEROTINIA CHECK LIST FOR CANOLA

This check list is intended to provide growers with background information to help them decide whether spraying their canola crop with a fungicide to control sclerotinia stem rot is economically justified. It is included in this publication for you to **better understand** the life cycle of this most important disease.

The time to fill out the checklist and make an assessment is shortly after first flower. First flower occurs when 75 per cent of the plants in the field have three open flowers on the main stem. In Alberta this usually happens around the last week of June and the first week of July. The answers to the questions are assigned points with the final tally indicating whether protection is economical.

STAGE ONE - Disease potential

1. Have you previously had a good crop at flowering and poor yields at harvest, even though growing conditions were favorable?

YES ________ 20
NO ________ 0

2. Have you seen sclerotinia rot in your crop in previous years?

YES ________ 20
NO ________ 10

3. Have you heard of stem rot problems in your area in the past 2 to 3 years?

YES ________ 20
NO ________ 5

4. Have you seen black sclerotes in your harvested seed in the past 2 to 3 years?

YES ________ 20
NO ________ 10

5. In previous years have your canola crops lodged?

HEAVILY ________ 20
MODERATELY ________ 0
LIGHTLY ________ 0

6. Do you see large swaths at harvest but get low yields?

YES ________ 10
NO ________ 0

7. If you sprayed a stem rot fungicide in previous years, what were the results?

BETTER CROP ________ 20
NO DIFFERENCE ________ 0

A high score of greater than 60 in the first stage, suggests that sclerotinia stem rot was probably present in previous years but may have gone undetected. Because of the past history of disease, the risk of a sclerotinia stem rot outbreak increases.

STAGE TWO - Disease development

8. At the beginning of the flowering period, if you walk through your crop during the late morning, are your boots and pantlegs wet from the moisture present?

YES ________ 20
NO________ 10

9. Have you had wet weather in the immediate area within 2 to 3 weeks prior to flowering that allowed the soil to remain moist for extended periods?

YES ________ 20
NO ________ 10

10. Were apothecia (tiny, golf-tee shaped mushrooms produced singly or in clusters by the sclerotia) found in the field, around the field, or in any neighboring cereal* or canola fields where canola was growing in the previous 1 to 3 years?

YES ________ 20
NO ________ 0

*Very heavy stands of cereal (e.g., 100 bu/ac barley) will promote soil surface conditions similar to dense stands of canola. If such a barley crop follows a canola crop that had sclerotinia in previous years, germinated sclerotia will be found at the base of the canopy. Air-borne spores from these germinated sclerotia can move into nearby stands of canola.

11. Do you believe the weather will remain dry throughout the flowering stage of the crop?

HIGHLY LIKELY ________ 0
MODERATELY LIKELY ________ 10
NOT LIKELY ________ 20

A score of greater than 50 on the second stage plus a high score on the first stage indictes that the conditions for rapid disease development exist.

STAGE THREE - Yield data

12. What is the condition of your stand in terms of height, vigor and uniformity?

EXCELLENT ________ 20
GOOD ________ 10
FAIR ________ 5
POOR ________ 0

13. When you walk through your crop, how dense is the canopy? Very dense canopies may retain a permanent dew (moisture) on the lower stems even during prolonged dry periods of two to three weeks in July. Under these conditions, even though the soil is dry, surface moisture is present from the dew. Sclerotes, at or on the surface under this very dense canopy, will germinate and form spore producing mushrooms (apothecia).

LIGHT ________ 0
MODERATE ________ 10
VERY DENSE ________ 20

14. What is the yield potential of the stand?

10-20 bu/ac ________ 0
20-30 bu/ac ________ 10
*Greater than 30 bu/ac ________ 20

*If your yield potential is greater than 30 bu/ac refer to question 15.

15. In previous years, when your yield potential was 30 bu/ac, what were your actual yields?

Greater than 30 bu/ac ________ 0
20-30 bu/ac ________ 20

If you consistently achieve high yields then your disease potential (actual levels) is low, therefore your score would be zero.

TOTAL ________

A score of greater than 50 in the last stage indicates the high yield potential of the crop. This, combined with high scores in the first and second stages, suggests that a protective fungicide application should be considered. With a score of less than 30 in the last stage, fungicidal application would not be worthwhile.

The above information is **not** intended as an endorsement for fungicidal disease control. It should be followed in order to gain an understanding of the factors that effect the actual or potential yield losses that this disease can cause.

Management Strategy- Avoid the disease.

Control Mechanism

- Follow a crop rotation that allows at least three to four years between susceptible crops. Sclerotes can remain viable for three or more years. Cereals, corn and grasses are immune, while mustard, field peas, beans, carrots, potatoes, lentils, soybeans, safflower, flax and clover, as well as many weeds, are susceptible to some degree to infection by this fungus.
- Use clean seed, free of sclerotes.
- Control volunteer crops and susceptible weeds in cereal crops.
- Swath early. This may reduce losses caused by shattering in canola.
- Do not exceed normal seeding rate and seed uniformly. Dense canopies promote disease development.
- High fertilizer inputs promote dense crop canopies that produce conditions that favor disease development.

In Canada, attempts to to control **Sclerotinia sclerotiorum** wilt of sunflowers and white mold of beans using mycoparasites (i.e., fungi that can attack sclerotinia) have met with some success. The fungi, **Coniothyrium minitans, Gliocladium catenulatum** and **Trichoderma viridae** were all able to infect and kill sclerotes of this fungus in the soil and thus reduce the sclerote population. All three fungi, however, were ineffective in controlling **Sclerotinia** in an active growing state and thus failed to reduce the spread of this disease. Further research needs to be done in this area of biological disease control.

STEM BREAK AND BROWNING
Polyspora lini (syn. Aureobasidium lini)

Biology - Browning and stem break are two phases of this disease.

Disease cycle - The fungus overwinters on the seed or infected crop residue. As the seed germinates and the seed coat is lifted above the soil by the cotyledon leaves, spores on the seed coat infect the new leaves. Wind and splashing rain spread the spores within the crop.

Disease development - The disease is favoured by warm humid conditions.

Symptoms - The browning phase generally appears late in the season. Plants develop grey-brown areas with purplish margins on leaves, stems and bolls. Affected plants usually appear in patches giving the crop a mottled look. Stem breaking which occurs throughout the season results from enlarging stem cankers caused by early infection.

Detrimental effects - There is a direct yield loss resulting from stem breakage. Seedlings may be killed if infected early. In some years this fungus is responsible for appreciable damage in the parkland regions of Alberta and Saskatchewan.

Yield loss is directly proportional to the percentage of broken stems per unit area.

Threshold levels - No data available.

Sampling - Check random areas of the field for this disease since it may affect the flax crop in widely scattered patches.

Management Strategy - Avoid disease-infected residue and sow disease free seed early.

Control Mechanisms

- Use a three-year crop rotation. This reduces infection derived from disease-infected residue.
- Use disease-free seed from flax crops produced in drier growing regions of the prairies.
- Seed early. This may result in a vigorous crop better able to withstand disease infection later in the season.

VERTICILLIUM WILT (leaf mottle)
Verticillium dahliae

Biology - Verticillium wilt can be a most destructive disease of sunflowers. It also affects many broad leaved weeds.

Disease cycle - This fungus overwinters in the soil and crop residue as tiny black resting bodies or sclerotes. These germinate and invade the root tips to produce more spores inside the plant tissue. Spores then move through the water conducting vessels to the above ground parts of the plant. Spores infect the head and seed and become seed-borne.

Disease development - This disease is favored by high moisture and cool temperatures.

Symptoms - Symptoms first develop on lower leaves and gradually move to higher leaves. Leaves becomes pale green, yellow, then brown, giving the mottled appearance. Black streaks may occur at the stem base. A cross section of the lower stem reveals a brown coloration of the water conducting tissue. Premature death may result. Diseased heads are small. Masses of tiny sclerotia are produced in infected plants.

Detrimental effects - Both seed yield and quality are reduced by this disease.

Threshold level - No data available.

Sampling - No procedure available.

Management Strategy - Resistant varieties and crop rotation.

Control Mechanism

- Use resistant cultivars.

RESISTANT -Cargill 204, Cargill 205, Cargill 206, DO 164, DO 844, Hybrid 894, Hybrid 7101, IS 775, Jacques 401, Jacques 501, NKX 1232, PAG SF 101, PAG SF 102, Sigco 450, Sigco 894A, Sigco 405, Sunbred 265.

INTERMEDIATE - Carona, Commander, Morden 12, Saturn, S-166, Sundak

- Use crop rotation - Sunflowers should not be grown more than once every five years even if the disease is assumed to be absent. The wilt fungus is known to persist for at least 12 years in infested soil.
- Control volunteers and broad leaved weeds.
- Use disease free seed.

FOLIAR DISEASES

DOWNY MILDEW (angular leaf spot)
Peronospora parasitica

Biology - This disease usually occurs with Staghead (white rust). Downy mildew can also infect seedlings and leaves of **Brassica campestris.**

Disease cycle - The fungus overwinters on stagheads and crop residue. In the spring, spores germinate and infect the leaves and newly formed stagheads.

Disease development - This disease is favored by cool wet spring weather.

Symptoms - The fungus appears as a white mealy growth on the lower surface of leaves and green stagheads. The upper leaf surface turns yellow.

Detrimental effects - This disease by itself causes damage of little economic significance. The combination of downy mildew and white rust has more yield-damaging potential.

Threshold levels - No data available.

Sampling - Examine the crop in the late rosette stage during cool, wet overcast weather.

Management Strategy - Reduce inoculum levels.

Control Mechanisms

- Use a crop rotation with noncruciferous crops.
- Control volunteer canola, stinkweed and wild mustard.

RUST
Melampsora lini

Biology - This rust affects both oilseed and fibre flax. It is different from cereal rust in that it does not require an alternate host. Its whole life cycle, including the sexual cycle, occurs on the flax plant. From the sexual cycle, new races of the disease are constantly evolving. A flax variety that was resistant a few years ago may now be susceptible to a newly developed race of the rust fungus.

Disease cycle - Spores overwinter on the crop residue. These germinate and produce small spores which infect the seedling flax leaves. Orange yellow pustules form and produce large quantities of summer spores that can infect surrounding plants. As the crop matures, the pustules turn a dark brown to form the overwintering spores.

Disease development - This disease is favored by warm, humid or wet conditions.

Symptoms - In June, pustules containing yellow spores appear on the undersides of the leaves. Later, larger powdery orange yellow pustules appear on leaves, stems and heads. As the plant matures, pustules form dark brown spores. These dark brown pustules develop on the stems and bolls, rarely on the leaves. Pustules in the black spore stage are often large and girdle the stem, extend vertically for several centimetres.

Detrimental effects - Flax rust may completely defoliate plants, resulting in reduced vigor, yield, and quality of seed and fibre. Stem breaking can also occur.

Threshold levels - Orange pustules showing up in the seedling crop can mean that under favorable weather conditions, a severe disease outbreak can occur.

Sampling - Examine the undersides of seedling leaves, particularly if the rust disease has been observed on your land in previous years.

Management Strategy - Use resistant varieties and reduce diseased residue.

Control Mechanisms

- Use resistant varieties.
- Use clean seed and remove any infested crop residue that might carry spores.
- Follow a crop rotation. Flax should not be planted on flax stubble and it should be planted as far from last year's flax crop as possible.
- Control volunteer flax.
- Plant early to help the crop mature before rust buildup becomes serious.
- Bury flax straw to decrease breakdown time and reduce rotation time.

POD, BOLL OR HEAD DISEASES

ASTER YELLOWS

A mycoplasma-like organism (MLO)

Biology - This disease affects canola, flax and sunflowers.

Disease cycle - See aster yellows of cereals.

Symptoms - Canola and related crops: Infected plants produce distorted sterile flower heads. Pods are replaced by oval, green bladder-like structures that remain green after the rest of the crop ripens.

Flax: Leaves on upper shoots are bright yellow and do not turn brown. Flower parts are leaf-like and greenish-yellow. Diseased plants may be stunted. Healthy and infected shoots can occur on the same plant.

Sunflower: Aster yellows usually affects only a portion of the head. Flowers grow larger than normal, remain green and do not set seed. The infected section turns brown and dies. Brown discolorations may extend down the stems and heads may break off.

Detrimental effects - Yield losses result through flower sterility.

Infections generally occur at trace levels, rarely at more than 2 per cent infection of the crop.

Threshold levels - No data available.

Sampling - Diseased plants are obvious as the crop approaches maturity.

Management Strategy - Minimize the effect of infection.

Control Mechanisms

Seed early to allow the crop to mature to a point where damage caused by the aster yellows organism is minimized.

BLACKSPOT (Alternaria black spot, grey leaf spot)

Alternaria brassicae, A. raphani

Biology - These fungi, present every year in canola growing areas, usually result in low levels of disease. The disease is most common in the Peace River and north-central regions of the prairies, particularly in Polish varieties.

Disease cycle - These fungi overwinter on infested crop residue, on the seed or on susceptible winter annual weeds (stinkweed). It is not uncommon in northern Alberta to have seed lots that are infested at a level of 20 per cent or more. Seed formed below a pod spot caused by this disease will become infected.

Disease development - Warm, humid conditions favor disease development.

Symptoms - Infected seedlings have dark spots on the cotyledons and first true leaves. Leaf spots range from grey to black depending on environmental conditions. Stem and pod lesions are small brownish-black dots, later becoming black or grey with a dark border. Infected pods may ripen prematurely and shatter while the crop is standing or in the swath.

Detrimental effects - Pod infections result in shattering and shrunken infected seeds. Yield losses of 20 per cent or more may result from the shattering.

Approximately each 1 per cent of stem and pod surface infected represents a 1 per cent yield loss.

Threshold levels - No data available.

Sampling - Check the amount of infection in the late green pod stage. Infected area refers to the amount of pod surface area covered with black dots.

Management Strategy - Prevent disease introduction and minimize losses through early swathing.

Control Mechanisms

- Rotate with noncruciferous crops.
- Control volunteer canola and cruciferous weeds in the rotation.
- Seed should be well cleaned to remove shrivelled infected seeds.
- Purchase seed from the drier regions of the prairies that carries less disease.
- Early swathing reduces losses from shattering.
- Argentine varieties are more resistant than Polish.

GREY MOLD HEAD ROT
Botrytis cinerea, Rhizopus spp.

Biology - Grey mold head rot is a disease of sunflowers.

Disease cycle - These fungi overwinter in crop residue or as tiny hard black overwintering bodies (sclerotes). The sclerotes germinate and produce spores which infect the heads of sunflowers. Moisture trapped on the backs of sunflower heads that are hanging downwards provides ideal conditions for infection.

Disease development - Cool temperatures (18-23 °C) are required for disease development, damp conditions for germination, spore production and infection. Grey mold head rot caused by **B. cinerea** typically occurs on maturing plants during wet weather in the fall. **Rhizopus** (a bread mold fungus) infections are encouraged by injuries from hail, insects and birds.

Symptoms - B. cinerea - A brown area appears on the back of the head and soft rot develops. Infested areas become grey with surface fungal growth. Seeds may be contaminated.

Rhizopus species - Irregular, water-soaked spots appear on the back of head, these enlarge and turn brown, until the whole head is soft and pulpy. Masses of surface-borne fungi with visible, stalked, black spore producing structures are present. This fungus can invade the seed.

Detrimental effects - Yield loss results from reduced seed yields. Contaminated seeds, resulting in seedling blight or poor germination, may seriously affect the following years' crop establishment and yield.

Threshold levels - No data.

Sampling - In a cross section of the crop inspect the flower heads as they approach maturity. Pest management

Management Strategy - Avoid inoculum.

Control Mechanism

- Use a crop rotation of three or more years.
- Turn under crop residues.
- Avoid harvesting delays if at all possible.
- Use a certified, disease free seed source.

STAGHEAD (white rust)
Albugo candida

Biology - Staghead or white rust only affects Polish canola; Argentine types are immune. With the introduction of the Polish variety Tobin, which is resistant to this disease, levels of staghead have fallen dramatically. Tobin occupies almost 100 per cent of the Polish canola acreage. The gene controlling staghead resistance occurs in 40 per cent of Tobin plants. In most years, this level of resistance seems to hold up but, in 1986 under very cool wet growing conditions in late June and July, up to 10 per cent levels of infection were observed in a few areas.

Disease cycle - This fungus overwinters as thick walled spores in the characteristic stagheads in the crop residue, or as pieces of stagheads contaminating seedlots. In spring, these spores germinate and infect canola seedlings. Infection results in white pustules on the underside of leaves, the white rust stage. These pustules release spores which can infect other leaves, stems and flowers. Stagheads result when the flower spikes are infected.

Symptoms - Pustules on the underside of the leaves are white to cream colored. These may be present from the seedling stage to maturity. Raised green pustules that turn white during wet periods may also form on leaves, stems and flower heads. Infected heads, which give this disease its name, stand out sharply in the crop. As the stagheads mature, they turn from green to white to brown and become hard and brittle.

Detrimental effects - Prior to the introduction of Tobin, losses of up to 20 per cent were recorded from this disease. Now losses from the staghead and white rust phases have been reduced dramatically.

Staghead may destroy from 5 to 90 per cent of the seed-producing potential of individual plants.

Threshold levels - No data available.

Sampling - Yield losses can be related directly to the percentage of staghead-infected spikes among the normal spikes.

Management Strategy - Use resistant varieties to reduce spore levels.

Control Mechanism

- Use resistant varieties.
- Follow a crop rotation with noncruciferous crops.
- Control volunteer canola and related cruciferous weeds.
- Use clean seed. Seed can become contaminated when stagheads break up during harvesting.

DISEASES OF FORAGE LEGUMES
(Alfalfa, Clovers)
SEEDLING AND ROOT DISEASES
CROWN AND ROOT ROT
Fusarium spp., **Pythium** spp., **Phoma** spp., **Rhizoctonia** spp., **Phytophythora megasperma**

Biology - Crown and root rot are the most common disease problems associated with alfalfa and clover. Occasionally, the disease is caused by just one fungus such as Phytophthora root rot but more often it is caused by a complex of organisms. This complex may include several genera, species or strains of fungi which interact with nonpathenogenic organisms and various environmental factors to cause rot.

Disease cycle - Each species may have some variation to this life cycle, but generally they overwinter in the soil or on plant residue. They enter the roots or crown directly or through wounds. The rot develops slowly in the taproot and crown but rapidly on smaller roots.

Disease development - Every fungus species has a set of conditions that favor its growth. Fusarium growth is enhanced by frost, poor drainage, low fertility, frequent harvests and foliar diseases. Crown bud rot caused by **R. solani, Fusarium** species, and **Phoma medicaginis,** is common after the second year of growth on irrigated or moist soils. Phytophthora root rot is most severe in cold, wet, poorly drained soil, especially during wet seasons or under irrigation. Foliar diseases, foliar and root insects, frequent or untimely cuttings, early frosts, poor fertility, severe winter conditions, low light intensity, and low soil pH are examples of stresses that encourage root rot.

Symptoms - Fusarium crown and root rot produces rusty-brown to dark brown streaks in the water conducting tissue of the root and crown. Large sections of the crown can be destroyed, leaving only a few side shoots alive.

Crown bud rot produces dark brown to black patches that occur on the bud tissue and move to the crown and upper root area.

Phytophthora root rot produces yellow brown patches on the tap root that may extend to the crown. Plants of all ages are susceptible but seedlings are particularly prone. Plants turn yellow, wilt and die.

Brown root rot **(Phoma sclerotioides)** produces circular light to dark brown areas spread throughout the roots and up to the soil surface. Black dots (pycnidia - spore producing structures) are present on the diseased areas. In the spring, stunted yellow plants often die after initial growth. Brown root rot, affects alfalfa, red clover, alsike clover, sweet-clover and bird's-foot trefoil. It also has been associated with a root rot of winter wheat and fall rye.

Detrimental effects - Crown and root rots affect the yield and life span of the stand. Loss of crown buds and stems lowers yield, thinning stands allowing weeds to invade, resulting in a poorer hay or seed quality.

Threshold levels - No data available.

Sampling - Look for this disease during late spring to early summer prior to crop flowering.

Management Strategy - Reduce the population of the disease organisms and avoid plant injury.

Control Mechanisms

- Use a crop rotation with resistant crops (cereals) for two to three years to reduce the fungus population.
- Maintain proper cutting schedules. Late summer/early fall cuttings do not give plants sufficient time to store nutrients necessary for winter survival. Cut the late crop immediately after a killing frost.
- Maintain adequate soil fertility, especially phosphorus and potash necessary to promote plant vigor.
- Avoid mechanical injury such as recurrent traffic over fields, which damages crown tissue.
- Grow the crop on well-drained soils.
- Provide adequate snow cover by trapping it with surface residue. This helps prevent winter cold injury.

Disease Control

WINTER CROWN ROOT ROT (Snow mold)
Coprinus psychromorbidus (LTB phase), Fusarium nivale, Typhula ishikariensis

Biology - These fungi infect all legumes and forage grasses. They are extremely widespread and can be especially damaging in the central and northern areas of Alberta and Saskatchewan where prolonged snow cover can be expected.

Disease cycle - The fungi survive in the soil until conditions are favorable for them to grow and infect the plant crowns. **Coprinus psychromorbidus** is active at temperatures near freezing while **Fusarium nivale** can become active as soon as plants are dormant.

Disease development - Prolonged snow cover favors disease development.

Symptoms - Dead plants in the field are the first indication of this disease. A dark brown rot appears on the crown tissue and affected plants may be killed.

Detrimental effects - Reduced yield results from reduced patchy stands.

Threshold levels - No data available.

Sampling - Look for this disease during late spring.

Management Strategy - Maintain a vigorous stand or a variety or mixture recommended for the region.

Control Mechanisms

- Use winter hardy varieties.

STEM DISEASES

BACTERIAL WILT -
Corynebacterium michiganense pv. insidiosum

Biology - Bacterial wilt causes losses in all alfalfa growing areas, but is most damaging in the irrigated areas of western Canada.

Disease cycle - Bacteria overwinter in the roots and residue of diseased plants. They are transported by soil and irrigation water to infect healthy plants through wounds in the roots and crown, or through the cut ends of newly swathed stems. Wounds can result from winter injury, nematode feeding, or mechanical injury. The bacteria multiply and block the water conducting tissues and eventually cause severe damage or death.

Disease development - This disease is favored by high humidity and is most severe on low lying, poorly drained land.

Symptoms - Diseased plants are usually scattered throughout a stand. Plants are stunted and light green. Stunting is more apparent during regrowth after cutting. Stems are shorter and leaves smaller and curled up at the edges. During warm dry spells, plants may wilt first at the tips, then the whole plant; death may follow. Winterkill is a problem with disease-weakened plants. A cross section of the tap root shows a brownish discoloration around the woody centre.

Detrimental effects - This disease lowers quality and quantity of hay and seed and reduces stand lifespan.

A 10 per cent infection can cause yield losses of 5-6 per cent since there is some compensation from adjacent healthy plants.

Threshold levels - No data available.

Sampling - Regrowth after the second cut will show how severe the infection is.

Management Strategy - Use disease resistant varieties and avoid reinfection.

Control Mechanisms

- Use resistant varieties.
- Stem nematodes may transmit bacteria. In the irrigated areas where both problems occur, use the nematode and bacterial wilt-resistant variety, Trek. Apollo II, Barrier, Trumpetor and WL316 are resistant to both bacterial and Verticillium wilt.
- Follow a crop rotation with no more than four consecutive years of alfalfa.
- Harvest young stands before old ones when using the same equipment.
- Thoroughly clean and disinfect mowers after cutting infested field.
- Avoid cutting when plants are wet.
- Do not over irrigate. Overflow water transports bacteria.

BLACK STEM (Spring and summer black stem)

Alfalfa - **Phoma medicaginis** var. **medicaganis** (syn. **Ascochyta imperfecta**)
Clover - **Phoma trifolii**
Sweet-clover - **P. meliloti**

Biology - This disease occurs in all alfalfa and clover growing areas of Canada. It is most destructive in warmer temperate regions.

Disease cycle - This disease overwinters on the seed, crop residue and in cankers on alfalfa and clover. Spores are produced in spring and are spread by water, wind and insects. New shoots are infected as they grow through the crop residue. During the summer, disease spread slows down, but may build up again in autumn. The fungus can survive on plant stems and seeds for approximately two years.

Disease development - This disease is favored by cool moist weather.

Symptoms - Black stem may infect all above-ground parts of the plant, including the crown and upper roots. In spring, small irregular dark brown to black spots develop on the lower stems and leaves. As these spots enlarge and join up, stems turn black and upper leaves, flowers and pods may drop.

Detrimental effects - Death of leaves and stems result in losses in quality and quantity of hay. Flower and pod drop causes seed yield losses.

Threshold levels - No data available.

Sampling - Look for this disease during late spring or early summer.

Management Strategy - Use resistant varieties, reduce inoculum levels.

Control Mechanisms

- Use resistant varieties.
  RESISTANT - sweet-clover - Brandon dwarf, Cumino, Erector.
  INTERMEDIATE - sweet-clover - Denta
  SUSCEPTIBLE - All others.
- Follow a crop rotation with nonlegume crops.
- Spring burning is sometimes recommended but may harm plants if new growth has already started.
- Use certified seed from a dry area which is less likely to contain infested seed.
- Cut early when the disease is prevalent to reduce leaf loss in the hay crop.

FOLIAR DISEASES

COMMON LEAF SPOT (Pseudopeziza leaf spot)
Pseudopeziza trifolii

Biology - Common leaf spot is a destructive disease of alfalfa and to a lesser extent of sweet-clover.

Disease cycle - The fungus overwinters on infected plants and crop residue. Spores produced in the spring are forcibly discharged into the air and carried by the wind to growing plants.

Disease development - The disease is favored by dense crop stands and cool, wet weather, particularly in early July.

Symptoms - Sharp brown circular spots develop on the leaflets. Older spots have a paler raised disc in the centre. Infected leaves turn yellow and drop before swathing.

Detrimental effects - Premature defoliation reduces plant vigor (winter hardiness), hay quality and yield.

Threshold levels - No data available.

Sampling - Look for this disease in late June.

Management Strategy - Use resistant varieties and reduce inoculum levels.

Control Mechanisms

- Use resistant cultivars.
- Harvest early. This reduces leaf loss and buildup of disease levels on the crop foliage.
- Harvest the crop cleanly to reduce the level of diseased plant residue.
- Control volunteer legumes in headlands. These legumes serve as reservoirs for this disease.

DOWNY MILDEW
Peronospora trifoliorum

Biology - This disease affects alfalfa, clovers and trefoil. Sweet-clover is seldom attacked.

Disease cycle - This fungus overwinters in the crown buds and in crop residue. Following infection, it grows internally throughout the plant. Spores produced by the fungus are spread by wind and rain. Youngest leaves are most susceptible to infection.

Disease development - Downy mildew is favored by wet or humid weather.

Symptoms - Chlorotic areas appear on the upper leaf surfaces with a grey layer of fungus on the undersides. Infected plants are stunted and leaves twist and pucker.

Detrimental effects - The presence of this disease lowers the quality of the hay and reduces yield, particularly in the first cut.

Threshold levels - No data available.

Sampling - No procedure available.

Management Strategy - Use resistant varieties and low inoculum levels.

Control Mechanisms

- Use resistant cultivars.
- Use crop rotation. This reduces disease build-up.
- Harvest cleanly to prevent re-infection from crop residue.
- Cut early. This may reduce leaf loss but will sacrifice yield.
- Burn stubble before spring growth begins. This can help in some instances.

GREY LEAF SPOT (Stagnospora leaf spot and root rot complex)
Leptosphaeria pratensis (asexual Stagnospora recederis, syn. S. meliloti)

Biology - This disease affects alfalfa and sweet-clover. In some areas, it is the most serious disease of sweet-clover. **L. pratensis** can also cause stem spots and crown and root rots.

Disease cycle - The fungus overwinters in the diseased crop residue and crowns of overwintering plants, and is spread by spores produced on infected leaves.

Disease development - Prolonged periods of wet weather in June and July favor disease build-up.

Symptoms - Leaf spots are large, oval areas with light centres and dark margins. Dead leaves tend to remain attached to stem. Light colored infection areas appear on the stems and petioles. Small black dots (pycnidia) form in the centre of the diseased spots. The fungus may attack the upper root and crown area producing a dark red-brown dry rot.

Detrimental effects - Losses are caused by leaf rot and loss of root functions. Hay yield and quality are reduced as well as plant vigor (winter hardiness). In most areas, Stagnospora leaf spot/root rot complex is a minor disease, but it can cause injuries which enable other disease organisms to become established.

Threshold levels - No data available.

Sampling - No procedure.

Management Strategy - Reduce inoculum levels.

Control Mechanisms

- Cut early. This reduces leaf damage and inoculum build-up.
- Burn the stubble before spring regrowth. This may help reduce inoculum levels.
- Follow a crop rotation with nonlegumes. This lowers disease potential.

POWDERY MILDEW
Erysiphe polygoni, E. trifolii

Biology - Powdery mildew is common on red clover in North America, but distinct strains of this fungus also affect alsike clover, sainfoin, alfalfa, trefoil and vetches.

Disease cycle - These fungi overwinter as small pinpoint black dots (resting structures) on diseased plant parts. During the spring, these resting structures produce spores that infect the leaves. Wind is responsible for secondary spread of spores produced on diseased plant parts during the growing season.

Disease development - Unlike most fungi, moderately dry weather favors development of this disease since wind blown spores do not need free water to infect the host.

Symptoms - A light dry powdery layer of the fungus is visible on upper surfaces of leaves, petioles and stems. Leaves turn prematurely yellow, then brown. Heavily diseased plants are usually stunted and unproductive.

Detrimental effects - Severe disease outbreaks lower the hay quality and reduce yields.

Threshold level - No data available.

Sampling - No procedure available.

Management Strategy - Reduce inoculum levels.

Control Mechanism

- Cut early. This may slow the spread but sacrifices the hay yield.

SOOTY BLOTCH (black blotch)
Cymadothea trifolii

Biology - This disease is common on alsike and white clovers and is sometimes found on red clover.

Disease cycle - This fungus overwinters on diseased plants. Spores are spread by wind, water and insects.

Disease development - This disease is favored by prolonged cool, moist conditions and is most prevalent in low wet areas.

Symptoms - Dark green blotches appear on the leaves which later turn black and sooty. Leaves wither when spots become numerous.

Detrimental effects - Hay and seed yield losses are caused by destruction of foliage and failure to flower. Severely infected foliage may be toxic to livestock causing ulcers of the mouth. Sooty blotch also affects the estrogen content of the leaves which may lead to reproductive disorders in animals fed infected material.

Threshold levels - No data available.

Sampling - No procedure.

Management Strategy - Reduce inoculum levels.

Control Mechanisms

- Use a crop rotation with nonlegumes for three years before re-seeding to clover.
- Harvest the crop cleanly. Cut the crop down to the crown area and completely remove the crop.
- Burn stubble in some instances.

TARGET SPOT (Stemphylium leaf spot)

Alfalfa - **Stemphylium botryosum.**
Red clover - **S. botryosum, S. sarcinaeforme**

Biology - This disease is common all over the Prairie Provinces.

Disease cycle - This fungi survives for years in plant residue or soil.

Disease development - This disease may cause significant losses in late summer in dense stands during wet weather.

Symptoms - Leaf spots are oval, slightly sunken, dark brown with light centres, and are usually surrounded by a pale yellow halo. Older spots often show distinct concentric rings hence the name target spot.

Detrimental effects - Target spot can cause losses of up to 50 per cent of the protein value of the crop by inducing heavy leaf drop.

Threshold levels - No data available.

Sampling - No procedure.

Management Strategy - Reduce inoculum levels by avoiding disease build-up.

Control Mechanisms

- Harvest early. This reduces losses in both quantity and quality of hay.
- Use a crop rotation with nonlegumes.

VERTICILLIUM WILT
Verticillium albo-atrum

Biology - Verticillium wilt has long been a serious disease of alfalfa in Europe but its establishment in the United States and Canada only occurred in the late 1970s.

Disease cycle - This fungus overwinters on infected plants, crop residue, seeds, and possibly on host weeds. The fungus enters the root system and grows in the water-conducting tissue of alfalfa. Spores are transported by wind, direct contact between plants, running water (irrigation), footwear, harvesting equipment, alfalfa hay, alfalfa seed, residue and insects.

Disease development - This disease is favored by high moisture and cool temperatures (18 °C)

Symptoms - Symptoms are most striking on the second growth following cutting. There is a yellow blotchiness on young leaves near the top of one or more stems on a plant. Closer inspection reveals V-shaped yellow or brown areas at the tip of the leaflets, centering the midveins. These areas become pale and dried out. Temporary wilting of upper leaves occurs on warm days. Although the leaves may be near death, the stem remains green and upright. Older severe infections cause stunting of infected plants. Under high humidity, the fungus may grow and produce spores on the outside of dead stems.

Detrimental effects - Verticillium wilt can reduce yields by 50 per cent or more by the end of the third crop year. Productive lives of infected stands are reduced to three-four years from five or more. Nutrient quality of hay produced does not seem to be affected.

The presence of Verticillium wilt in a region endangers important export opportunities for dehydrated alfalfa, pedigree seed and leafcutter bees (leafcutter bees have been shown to use infected alfalfa leaves to build their cocoons - cocoons with immature bees are sold to other countries).

Threshold levels - There are no tolerance levels when testing for this disease, one plant or seed sample with this disease and the shipping and treating restrictions apply.

Sampling - Field inspections should be handled by the producer as follows: walk each field randomly, when there is approximately 25-30 cm of plant growth, and just prior to flowering. Plants showing symptoms of the disease should be tested at a disease diagnostic centre.

Management Strategy - Prevent introduction of the disease onto clean land and eradicate if possible or grow resistant varieties.

Control Mechanisms

- Use resistant varieties.
- Use clean, disease free, pedigreed seed to start new alfalfa fields. Plant on weed-free land that has not grown alfalfa for the past three years. Shepherd's-purse, redroot pigweed, lamb's-quarters and dandelions are susceptible to this disease.
- Badly infested fields should be plowed under.
- Keep stands vigorous by following proper irrigation, weed control and fertilization practices.
- Treat alfalfa seed with bacterial Rhizobium inoculant - encourages proper nodulation and vigorous growth through its ability to fix nitrogen.
- Clean plant debris from harvesting equipment and disinfect with steam or a 2 per cent formaldehyde solution.
- Do not graze livestock on infected fields. Verticillium fungus can be spread in the manure. Do not spread contaminated manure from livestock feeding on infected alfalfa onto forage fields.
- The verticillium fungus remains viable after dehydration.
- Irrigate disease-free fields first.
- Control insect vectors.

Agriculture Canada has amended their compulsory seed treatment program. It now allows sale and movement of seed lots without fungicidal treatment, providing they are diagnosed to be free of **V. albo-atrum.** It is the responsibility of the person producing/moving the seed to determine that it is free of this disease. Infested seed or seed not known to be free of this disease must be treated with Thiram, disposed of for sprouting purposes, or destroyed.

YELLOW LEAF BLOTCH
Leptotrochila medicaginis

Biology - Yellow leaf blotch is a major leaf disease of alfalfa, and is common in central and northern prairie regions.

Disease cycle - The fungus overwinters on crop residue. Spores are released during the spring and infect new growth. Resulting blotches do not produce spores until the following spring.

Disease development - Disease incidence is highest when periods of wet and hot dry weather alternate.

Symptoms - Symptoms are most prevalent in late spring and early summer. Elongate yellowish blotches appear parallel to leaf veins on the leaves, stems and petioles. Black dots (pycnidia) appear on the diseased leaf surface and infested leaves curl downward before they dry up and fall.

Detrimental effects - Premature defoliation reduces vigor, hay quality and yield.

Threshold - No data available.

Sampling - No procedure available.

Management Strategy - Use resistant varieties and reduce inoculum levels.

Control Mechanisms

- Use resistant cultivars.
- Cut early to reduce losses and reduce build-up of infected leaves.
- Burn carefully in spring.
- Use a crop rotation with cereals.

VIRAL DISEASES

Biology - There are many types of virus and virus-like diseases that affect forage legumes. Each disease may differ symptomatically, but because disease cycles and control measures are similar, they will be dealt with as a group.

Disease cycle - Viruses can be transmitted by insect vectors, mechanical damage, plant to plant contact, pollen and seed.

Alfalfa mosaic virus (AMV) is transmitted primarily through the seed, 2-31 per cent of the seed produced by an infected plant is infected. It also can be transmitted by aphids especially the pea aphid **(Acyrthosipon pisum)** and the green peach aphid **(Myzus persicae)**. Other aphid transmitted viruses are bean yellow mosaic virus (BYMV), pea streak virus (PSV) and red clover vein mosaic virus (RCVMV). Lucerne transient streak virus (LTSV) is spread only by mechanical transmission. No vectors or seed transmission have been observed.

Viruses that are transmitted mechanically and by insect vectors overwintering in infected wild and cultivated legumes. Perennial legumes such as vetch and medic serve as reservoirs for AMV.

The vast majority of the insect vector species do not survive the winter and must be blown in annually from the United States. Some of these migratory insect species may already be carrying viruses or MLOs that will infect forage legumes.

Disease development - Build-up depends on the presence of infective aphid or leafhopper vectors.

Symptoms - Viral diseases produce many types of symptoms. The most common symptom is stunting or dwarfing of the entire plant or foliar symptoms such as mosaics. These discolorations may be further described as mottling (AMV or BYMV), streaking (LTSV), or vein clearing (CYMV). Some virus diseases are symptomless in their hosts.

Detrimental effects - All viral diseases cause a reduction of total yield as well as shortening the life span of the stand. AMV can cause up to 30 per cent loss in forage yield and up to 54 per cent reduction in dry matter content. LTSV has caused up to 18 per cent reduction of dry matter in alfalfa. Viral infections can also reduce root nodulation and winter survival of plants.

Threshold levels - No data available.

Sampling - No procedure available.

Management Strategy - Little can be done economically to control these diseases. Generally, they take from two to many years to build up and along with fungal and bacterial diseases they are responsible for the gradual loss of productivity of legume crops. Stands that become nonproductive after a number of years should be plowed under and replaced with nonlegumes in the rotation.

HEAD DISEASES

LEAF PROLIFERATION

Clover phyllody (mycoplasma-like organism) and Clover proliferation (MLO)

Biology - These diseases occur on alsike, red, white and sweet-clovers and bird's-foot trefoil. They are transmitted by leafhoppers **(Aphrodes bicinctus** and **Macrosteles fascifrons)**.

Disease cycle - These diseases are spread only by leafhoppers. Once these hoppers become infective they remain so until their death. MLOs overwinter in infected biennial and perennial plants.

Disease development - Spread is dependent on the number of infective leafhoppers present.

Symptoms - Phyllody - Flower parts revert to leaf-like structures. Petals are reduced and green and the ovaries are replaced by leaves. Plants are stunted and a light yellow color.

Proliferation - Profuse foliar growth appears from the crown giving a witches' broom appearance. Flowers are green and modified in shape. Each flower becomes a cluster of green leaf-like appendages.

Detrimental effects - No seed is produced by infected heads. Infected plants do not usually survive the winter, so the stand dies out.

Threshold levels - No data available.

Sampling - The percentage of witches' broom present during the growing season is an indication of the amount of die-off to be expected overwinter.

Management Strategy - No practical control is known.

Control Mechanism

- When stands become unproductive, cultivate and replace with a nonlegume crop in the rotation.

DISEASES OF POTATOES

Biology - There are approximately 40 infectious diseases of potatoes in Canada

Disease cycle - Potatoes are one of the few field crops that are not planted from true seed. Seed potatoes are vegetative storage organs that are grown year after year. Through such vegetative propagation, many diseases can be transmitted from generation to generation.

Potatoes are susceptible to many types of diseases caused by viruses, bacteria, mycoplasmas, nematodes and fungi. In order to keep a potato variety relatively free of disease, it has to go through a stringent seed potato program. In Canada, this program is administered by the federal Government under strict guidelines whereby potato varieties free of all known diseases are produced under the laboratory and are grown for up to six generations by seed potato growers under strictly regulated conditions before they become available for commercial planting as certified potato stock. Certified potatoes must be absolutely free of some diseases such as bacterial ring rot or spindle tuber virus, but can contain minimal or trace levels of many other diseases, such as potato leaf roll virus or bacterial blackleg.

Disease development - Each disease organism has its own favored conditions in which to grow. With the proper interaction between environment and disease, a slow build-up or an epidemic can result.

Symptoms - Fungal diseases - Symptoms range from surface scabs or scurfs, dry and soft rots to malformations of the tubers. The foliage (vines) arising from potato tubers may be affected by leaf spots, blights and wilts.

Bacterial diseases - Infection may occur in or on the tubers, causing symptoms ranging from skin discoloration to dry and wet rots. Bacterial ring rot is a devastating, highly infectious disease of potatoes, so much so that in Alberta there has been legislation since 1939, saying that a grower must control this disease by law (The Agricultural Pests Act revised 1987).

Viral diseases - These diseases range from symptomless mild infections such as in the case of potato virus X to potato leaf roll which drastically reduces potato yield and quality. Virus diseases are spread by plant to plant contact or by aphids.

Mycoplasma diseases - These diseases are sporadic and generally of little importance on prairie grown potatoes. They are spread by several species of leafhoppers.

Nematode diseases - Nematodes are controlled by strict quarantine regulations. The golden potato nematode exists only in Newfoundland and Vancouver Island. Since this nematode is spread only through contaminated soil it is illegal to move potatoes from those areas to other parts of Canada.

Detrimental effects - Some of these diseases do not have any effect on eating quality, but diseases such as common scab or silverscurf make the potato unattractive to consumers. Fusarium dry rot causes serious losses for growers and shippers because under certain conditions, potatoes that were certified healthy may develop rot in transit. Rhizoctonia can be responsible for losses that average 15 per cent, but in some years entire fields are lost. Severe verticillium wilt of potatoes can reduce yields by 20 per cent or more.

Bacterial ring rot is one of the most serious diseases of potatoes in Canada. It is highly infectious and fields are rejected for certified seed if one diseased plant is found. Losses in table stock may also be high because ring rot infected tubers rot in the field and in storage. Bacterial soft rot usually occurs in association with other diseases such as late blight, leak, pink rot and blackleg. It may follow freezing injury and may be serious in storage or transit if humidity and temperature are not properly maintained. In wet years it may cause considerable damage.

Viral diseases generally do not affect the eating or selling quality of potatoes for table stock. They do affect size and number produced. They are however, the main cause of rejection of fields intended for seed. Reduction in marketable yield corresponds to the reduction in size and vigor of the infected plants.

All potato diseases are of some economic significance because losses are able to show up in more than one area. Disease problems in the field cause direct yield losses, but they can also cause further losses in storage, reduced marketing quality, seed performance or yielding ability.

Threshold levels - Bacterial ring rot was declared a pest under The Agricultural Pests Act of Alberta in 1939. All grades of Canadian seed potatoes have a zero tolerance level for bacterial ring rot. The aim is to eradicate the disease on all commercial potato farms in Canada. There is also an amendment to The Canada Seeds Act that calls for zero tolerance for spindle tuber virus in all classes of seed potatoes.

Management Strategy - Use sanitation measures and resistant varieties and eradication.

Control Mechanisms

General disease control for potatoes

- Plant certified disease-free potatoes in disease-free soil, using whole tubers whenever possible.
- Disinfect storages annually and potato equipment between individual seed lots. Disinfect cutting knives frequently since contaminated knives can transmit many potato diseases to otherwise healthy tubers.
- Follow a crop rotation of at least three-four years.
- Harvest tubers when mature, when soil temperatures are less than 20 °C but not lower than 7 °C.
- Minimize mechanical damage during harvest and handling. Avoid harvesting potatoes when soil is close to freezing since they bruise very readily at this temperature.
- Store tubers for seven-ten days at 12 °C (10 °C for processing potatoes). Maintain humidity at 90 per cent with adequate ventilation so that wounds resulting from harvesting can heal (suberize).
- Do not wash tubers before storing. If necessary dry as soon as possible and package in well aerated containers. Use clean water and change wash water frequently when tuber cleaning is necessary.
- Bury crop residue and potato culls.
- Rogue fields, that is remove infected plants from seed plot areas and destroy tubers as soon as they are spotted.
- Follow good soil management including recommended irrigation practices.
- Control weeds between rotations particularly those in the potato family such as wild tomatoes.
- Avoid planting into cold wet soil and cover seed potatoes with no more than 5 cm (2 in.) of soil.

DISEASES OF PULSE CROPS

There has been a steady increase in the acreage of pulse crops (edible grain legumes, particularly peas) in recent years. This is the result of new markets for human and animal consumption, newly adapted varieties for prairie conditions, and the acceptance of these new crops as break crops in rotations.

The lack of disease resistance in many pulse crops makes it necessary to use cultural methods as a primary means of disease control. Cultural control consists of sound management practices to improve growing conditions, combined with the use of resistant varieties when they are available.

Plant clean certified disease-free seed on uninfested land to ensure that no new diseases are introduced. Seed-borne diseases such as Ascochyta blight of fababeans and peas and Anthracnose of beans are controlled this way.

Use rotations with cereal crops. This will allow the pulse crop residue to break down, reducing the levels of short term soil-borne diseases such as root rots, seedling blights, Sclerotinia, and chocolate spot of fababeans. Broadleaf crop volunteers and weeds must be controlled in combination with rotations to destroy all hosts upon which the diseases may survive.

Use proper sanitation, including removing diseased plants and plowing under infected plant material. Control volunteer plants to prevent disease build-up. Plow under infected crop residue to control diseases like powdery mildew on fababeans, Anthracnose or common blight on field beans. Till to reduce disease by burying crop infested residue to allow faster decomposition and destruction of the material by soil microorganisms. Tillage reduces movement of fungal spores by wind and allows greater root penetration, which helps beans to form a deep root system to escape fusarium root rot infection.

Use good growing practices to promote vigorous healthy seedlings. Tillage will control diseases and weeds as well as prepare a proper seedbed. Plant seeds as shallow as possible to conserve seedling energy in growing the extra distance to the surface, and to give less time for the seed and seedling diseases to infect. Avoid close plant spacing and overfertilization with nitrogen; both promote dense heavy canopies that provide the moist humid environment that encourages leaf diseases and sclerotinia white mold. Use soil testing to determine the amount of fertilizer needed. Plant seed on well-drained land to minimize soil-borne diseases. Excessive irrigation will increase most foliar diseases, while powdery mildew may be reduced by the application of water. Avoid cultivating or entering fields during wet weather or while dew is still on the foliage. This will help reduce the spread of anthracnose and bacterial diseases which require water on the leaf for infection. Avoid planting new fields near previous crops to reduce infestation by wind blown spores. This practice is recommended for Mycosphaerella blight and powdery mildew of peas. Use proper care in harvesting the dry seed of pulse crops. Adjust combines properly to avoid damaging seed coats and to remove crop residue in the seed that may carry disease.

Pulse crops are members of the legume family which includes forage crops such as alfalfa, clovers and sainfoin. Legumes are able to form a mutually beneficial relationship with certain strains of soil bacteria called **Rhizobium.** Rhizobia invade the roots of legumes where they cause swelling or nodulations. They are able to take gaseous nitrogen from the soil and convert it to a form that is available to the plants. Legumes in return supply sugars and carbohydrates to the bacteria. Rhizobia are capable of fixing 60-200 lb/ac of nitrogen; therefore little to no nitrogen fertilizer may be needed.

Strains of Rhizobium bacteria occur naturally in soils but in many instances the most effective strain for given legume species may be absent.

Legume seeds should therefore be inoculated with the approriate strain of **Rhizobium** to ensure early and proper nodulation. Plants which are inoculated are healthier and are better to cope with diseases.

Use resistant varieties. Resistance is the most economical and efficient means of disease control.

Fababeans - Ascochyta leaf and pod spot

RESISTANT - none
INTERMEDIATE - Akerperle
SUSCEPTIBLE - All others

Field beans - Anthracnose

RESISTANT - Ex Rico 23, Fleetwood, Kentwood, Seafarer
SUSCEPTIBLE - All others

Halo blight

RESISTANT - Fleetwood, Kentwood, Seafarer
INTERMEDIATE - Red Mexican, and Great Northern types
SUSCEPTIBLE - All others

Stem rot (white mold)

RESISTANT - none
Varieties with a compact upright growth habit i.e., Navy beans allow better air circulation providing less favorable conditions for white mold
INTERMEDIATE - Ex Rico 23

Bean Yellow Mosaic Virus (BYMV) and Bean Common Mosaic Virus (BCMV).

RESISTANT - Seafarer

Lentils - Ascochyta blight

RESISTANT - none
INTERMEDIATE - Laird

DISEASES OF SUGAR BEETS

Sugar beets are grown in the irrigated parts of the southern prairies. All commercial fields are grown under contract with a processing company.

Sugar beets should only be grown once every four years in a rotation with cereal crops to avoid damage caused by the sugar beet cyst nematode **(Heterodera schachtii)**. Canola, mustard or cruciferous weeds are also hosts to this disease and should not be grown or allowed to volunteer in this four year rotation. Sugar beet fields are monitored annually and those that are found to be infected with **H. schachtii** are taken out of production. Sugar beets can also be affected by damping-off, seedling blight or blackleg. These can be controlled by planting sugar beets into a firm, moist seedbed. There are only a few foliar diseases that affect this crop on the prairies. Leaf spot **(Cercospora beticola)** and powdery mildew **(Erysiphe polygoni)** are the most common. Leaf spot rarely occurs on the prairies and can be controlled by crop rotation, turning under crop residue and locating new fields at least 100 m from infected fields. Powdery mildew spores arrive from the southern United States generally too late to affect yields appreciably.

DISEASES OF SAFFLOWER

Safflower is a source of high protein edible oil and is also used for birdseed. It has a long taproot that allows it to be grown in dryland conditions. When placed in a cereal rotation, it can be used to break the cycle of foliar diseases.

Safflower is affected, in order of greatest yield loss potential, by Sclerotinia head rot, Alternaria leaf spot and rust. Crop rotation, turning under crop residue and avoiding planting near previously infested fields will help control these diseases.

Varietal resistance to specific barley diseases

* = 2 and 6 rows recommended for Alberta

\- = reaction unknown

	Common Root Rot	Covered/False Loose Smut	Ergot	Leaf Stripe	Loose Smut	Net Blotch	Scald	Speckled Leaf Blotch	Stem Rust
Abee (2)*	I	I	I	R	S	S	S	S	S
Argyle *	R	S	I	I	I	S	S	S	R
Beacon	I	S	-	S	S	S	S	S	R
Bedford	I	I	-	I	S	I	S	S	R
Betzes (2)*	I	S	S	R	S	S	S	S	S
Bonanza*	I	S	I	R	S	S	S	S	R
Centennial (2)	S	S	-	-	S	S	S	S	S
Conquest*	I	I	I	I	I	S	S	S	R
Deuce (2)*	I	R	-	-	S	S	S	S	R
Diamond*	S	R	I	R	S	I	S	I	R
Duke*	I	I	-	-	S	S	R	S	R
Ellice (2)*	I	S	-	-	I	I	S	S	R
Elrose (2)	I	I	-	S	S	S	S	S	S
Empress *	I	S	-	-	S	S	I	S	R
Fairfield (2)	I	I	I	R	S	S	S	S	S
Galt *	S	R	S	I	S	S	S	R	R
Gateway 63	S	I	-	I	S	S	S	S	-
Harrington (2)*	I	S	I	S	S	S	S	S	S
Heartland *	I	I	I	I	S	R	S	S	R
Hector (2)	I	I	S	I	S	S	S	S	S
Herta (2)	I	-	-	I	S	S	S	S	S
Jackson *	S	S	S	S	S	S	S	S	S
Johnston *	I	S	I	S	S	S	R	S	R
Klages (2)*	I	R	I	-	S	S	S	S	S
Klondike *	I	I	S	S	S	S	S	S	R
Leduc*	I	R	I	I	I	I	I	S	R
Melvin*	S	I	S	I	S	S	S	S	R
Noble*	S	R	-	-	S	S	S	S	R
Norbert (2)	S	S	S	I	S	R	S	S	R
Otal *	S	S	S	S	S	S	S	S	S
Peguis	I	S	-	S	S	S	S	S	R
Samson *	I	I	I	-	S	S	S	S	I
Scout (Hulless-2)*	I	S	I	R	S	S	S	S	S
Tupper (Hulless-6)*	I	S	I	-	I	S	S	S	R
Virden	-	-	-	-	-	-	-	-	R
Winchester *	I	R	-	-	I	I	R	S	S

Varietal resistance to specific wheat diseases
* = recommended for Alberta
\- = reaction unknown

	Barley Yellow Dwarf	Common Bunt	Common Root Rot	Ergot	Leaf Rust	Loose Smut	Powdery Mildew	Stem Rust	Stripe Rust
Hard Red Spring									
Benito	S	I	I	I	R	R	-	R	R
Bluesky*	-	I	R	-	R	R	-	R	-
Canuck	S	I	S	I	S	I	-	S	R
Chinook	S	I	I	-	S	S	-	S	R
Columbus *	S	I	I	I	R	I	-	R	R
Conway *	S	S	I	-	S	R	-	R	R
Garnet	S	S	-	-	S	S	S	S	R
Glenlea *	S	I	R	S	R	R	-	R	R
Katepwa *	S	I	I	I	I	R	-	R	R
Kenyon *	S	I	I	-	R	I	-	R	R
Lancer *	S	R	I	-	R	R	-	R	R
Laura	-	S	I	I	R	I	-	R	R
Leader *	S	I	S	I	S	I	-	S	R
Manitou	S	I	I	-	S	R	-	S	R
Napayo	S	I	I	-	I	R	-	R	R
Neepawa *	S	I	I	I	I	R	-	R	R
Park *	S	I	I	I	S	R	-	S	R
Pitic 62 *	S	S	I	S	I	S	-	S	R
Roblin *	-	I	I	-	R	R	-	R	R
Saunders	S	I	I	-	S	R	-	S	R
Selkirk	S	R	I	-	I	R	-	R	R
Sinton	I	I	I	I	R	S-	R	R	
Thatcher	S	I	I	I	S	R	-	S	R
Wildcat*	-	S	I	-	R	R	-	R	-
Durum									
Arcola *	S	R	I	-	R	I	-	R	S
Coulter *	S	R	I	S	R	I	-	R	S
Hercules	S	R	I	S	R	I	-	R	S
Kyle *	S	I	I	-	R	S	-	R	S
Macoun	S	R	I	I	R	I	-	R	S
Medora *	S	R	I	S	R	S	-	R	S
Pellisier	S	I	I	-	S	I	-	S	S
Sceptre *	S	R	I	-	R	S	-	R	S
Wakooma *	S	R	I	I	R	I	-	R	S
Wascana	S	R	I	I	R	I	-	R	S
Prairie Spring									
HY320 *	S	S	I	I	R	S	-	R	S
Oslo*	S	I	I	-	R	S	-	R	-
Winter									
Norstar *	S	S	I	I	S	S	-	S	S
Norwin *	S	S	I	-	S	S	-	I	I
Sundance *	S	I	I	I	S	S	-	I	S
Soft White Spring									
Fielder *	S	S	I	I	S	S	I	S	S
Owens *	S	S	R	I	S	S	I	S	R

Varietal resistance to specific oat diseases
* = recommended for Alberta

	Covered/ Loose Smut	Crown Rust	Stem Rust	Grey Speck
Athabasca *	S	S	S	S
Calibre *	S	S	S	S
Cascade *	S	S	S	S
Cavell	S	S	S	S
Dumont *	R	R	R	S
Fidler	R	R	R	I
Foothill *	S	S	S	S
Fraser	I	S	S	S
Garry	I	S	S	S
Gemini	I	S	S	S
Grizzly *	S	S	S	S
Harmon *	I	S	S	S
Hudson	I	I	I	I
Jasper *	S	S	S	S
Kelsey	I	S	S	S
Random *	S	S	S	I
Riel	R	R	R	S
Rodney	I	S	S	S
Sioux	I	S	S	S
Terra (hulless)	S	S	S	I

Varietal resistance to specific rye diseases
* = recommended for Alberta - = reaction unknown

	Stem Smut	Snow Mold
Cougar *S	S	
Gazelle * (spring)	-	-
Kodiak *	R	I
Muskteer *R	I	
Prima *	I	I
Puma	I	S

Stem smut is most prevalent under cool moist conditions especially on sandy soil, therefore not generally a problem on spring rye.

Varietal resistance to specific canola diseases
* = recommended for Alberta - = reaction unknown

	Alternaria Black Spot	Blackleg	Sclerotinia Stem Rot	Common Root Rot	White Rust/ Staghead
B. napus					
Global	S	S	S	S	R
Pivot*	S	S	I	I	R
Tribute*	S	S	S	S	R
Triton*	S	S	I	S	R
Regent	S	S	S	S	R
Stellar	S	#	S	S	R
Westar*	S	S	S	S	R
B. campestris					
Candle	VS	S	S	S	S
Tobin*	VS	S	S	S	R

= Similar to Westar in its seedling reacton but superior to Westar under normal field conditions.

Varietal resistance for specific flax diseases
* = recommended for Alberta

	Rust	Wilt
Culbert	R	R
Dufferin*	R	R
Linott	R	R
McGregor*	R	R
Noralta*	S	R
NorLin*	R	R
NorMan*	R	R
Raja	R	S
Redwood 65	S	R
Vimy*	R	R

Varietal resistance for specific triticale diseases
* = recommended for Alberta - = reaction unknown

	Common bunt	Common root rot	Ergot	Leaf rust	Stem rust	Loose smut
Spring						
Carman*	R	I	S	R	R	R
Wapiti*	R	I	I	R	R	I
Welsh*	R	S	I	S	R	I
Winter						
Aurora*	-	-	-	-	-	-
Decade*	-	-	-	-	-	-
Wintri*	-	-	-	R	-	-

Varietal resistance to specific field pea diseases
* = recommended for Alberta - = reaction unknown

	Ascochyta leaf and pod spot *A. pisi*	Ascochyta foot rot *A. pinodella*	Ascochyta or Mycosphaerella blight *M. pinodes*	Bacterial blight	Powdery mildew	Downy mildew	Sclerotinia	Septoria leaf spot
Bellevue	-	-	S	-	S	-	-	S
Century*	R	-	S	-	I	-	-	S
Express	-	-	S	-	-	-	-	-
Fortune	-	-	S	-	I	-	-	-
Lenca	-	-	S	-	I	-	-	-
Tara	-	-	S	-	R	-	-	S
Tipu*	-	-	S	-	S	-	-	-
Titan*	-	-	S	-	S	-	-	-
Trapper*	-	-	S	-	I	-	-	S
Triumph*	-	-	S	-	S	-	-	-
Victoria*	-	-	S	-	-	-	-	-

Varietal resistance to specific alfalfa diseases

* = recommended for Alberta

\- = reaction unknown

	Bacterial Wilt	Black Stem	Common Leaf Spot	Downy Mildew	Verticillium Wilt	Winter Crown Rot	Yellow Leaf Blotch
Admiral*	R	-	-	-	R	-	-
Algonquin*	R	-	-	R	-	-	-
Ambassador	R	-	-	-	R	-	-
Anchor*	R	-	-	-	-	-	-
Angus*	R	-	-	R	-	-	I
Anik*	S	-	-	R	-	R	R
Apica*	R	-	-	-	-	-	-
Apollo II	R	-	-	-	R	-	S
Award*	R	-	-	-	S	-	-
Barrier*	R	-	-	-	R	-	-
Beaver*	R	R	-	I	-	-	I
Citation*	R	-	-	-	-	-	-
Dekalb 120*	R	-	-	-	-	-	-
Drylander*	R	-	-	S	-	I	-
Eagle	R	-	-	-	I	-	-
Excalibur	R	-	-	-	R	-	-
Grimm	-	-	-	-	-	I	-
Heinrichs*	R	-	-	-	-	-	-
Iroquois	R	R	R	-	-	-	-
Pacer*	R	-	-	-	-	-	-
Peace*	S	-	-	-	-	I	S
Pioneer 524	I	-	-	-	-	-	-
Pioneer 532	R	-	-	-	-	-	-
Roamer*	R	-	-	I	-	I	-
Saranac	R	-	-	-	-	-	-
Spredor 2*	R	-	-	-	-	-	-
Thor*	R	-	-	R	-	-	I
Titan*	R	-	-	-	-	-	-
Trek*	R	-	-	I	-	-	S
Trumpetor*	R	-	-	-	R	-	-
Vernal*	R	R	-	I	-	-	I
Vista*	R	-	-	-	-	-	-
Vertus	S	-	-	-	R	-	-
WL 316	R	-	-	-	I	-	-
88	-	-	-	-	R	-	-

Canola/rapeseed diseases in Alberta

	White rust staghead	Sclerotinia stem rot	Black spot	Blackleg	Root rots seedling blights	Greystem
Resistance	Yes	No	No	No	No	No
Overwinters in soil or on trash	Yes	Yes	Yes	Yes	Yes	Yes
Longevity in soil	5 yr	3-4 yr	2-3 yr	2-5 yr	S	2-3 yr
Other hosts	Mustard weeds	Many	Mustard weeds	Mustard weeds	Many	Mustard weeds
Risk of infection from outside	Low	Mod	High	High	Low	Low
Rotation Effectiveness	+	+	+	+	+	+

S = soil borne organism

In the last few years, considerable attention has been focussed on canola/rapeseed crops worldwide and new information has come to light. It seems that rape, particularly rape with high levels of glycosinolate, used as a green manure crop, will control a number of soil-borne diseases. In France, green manure rape is used to control the golden cyst nematode before planting potatoes, and in New Zealand green manure rape controls **Aphanomyces** root rot of the following pea crop. The active ingredient in this disease control appears to be a breakdown product of glycosinolate present in the rape that is released into the soil. The glycosinolate breaks down into an isothiocyanate chemical. A very similar chemical (methylisothiocyanate) is the ingredient in the commercially available soil fumigant Vorlex.